AD-671662

USAAVLABS TECHNICAL REPORT 67-9C

IN-FLIGHT MEASUREMENT OF ROTOR BLADE AIRLOADS, BENDING MOMENTS, AND MOTIONS, TOGETHER WITH ROTOR SHAFT LOADS AND FUSELAGE VIBRATION, ON A TANDEM ROTOR HELICOPTER

VOLUME III

DATA PROCESSING AND ANALYSIS SYSTEM

By

John W. Obbard

November 1967

U. S. ARMY AVIATION MATERIEL LABORATORIES
FORT EUSTIS, VIRGINIA

CONTRACT DA 44-177-AMC-124(T)
VERTOL DIVISION
THE BOEING COMPANY
MORTON, PENNSYLVANIA

Disclaimers

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission, to manufacture, use, or sell any patented invention that may in any way be related thereto.

Trade names cited in this report do not constitute an official endorsement or approval of the use of such commercial hardware or software.

Disposition Instructions

Destroy this report when no longer needed. Do not return it to the originator.

DEPARTMENT OF THE ARMY
U. S. ARMY AVIATION MATERIEL LABORATORIES
FORT EUSTIS, VIRGINIA 23604

This report, Volume III of five volumes, has been reviewed by the U. S. Army Aviation Materiel Laboratories and is considered to be technically sound. The work was performed under Contract DA 44-177-AMC-124(T) for the purpose of measuring the dynamic air pressures on the blades of a tandem rotor helicopter and the resulting blade and shaft stresses and fuselage vibration during flight. The report is published for the dissemination and application of information and the stimulation of ideas.

Task 1F125901A14604
Contract DA 44-177-AMC-124(T)
USAAVLABS Technical Report 67-9C
November 1967

IN-FLIGHT MEASUREMENT OF ROTOR BLADE AIRLOADS, BENDING MOMENTS, AND MOTIONS, TOGETHER WITH ROTOR SHAFT LOADS AND FUSELAGE VIBRATION, ON A TANDEM ROTOR HELICOPTER

VOLUME III

DATA PROCESSING AND ANALYSIS SYSTEM

D8-0382-3

by

John W. Obbard

Prepared by

VERTOL DIVISION
THE BOEING COMPANY
Morton, Pennsylvania

for

U.S. ARMY AVIATION MATERIEL LABORATORIES
FORT EUSTIS, VIRGINIA

SUMMARY

An extensively instrumented tandem rotor helicopter was flight-tested to measure the rotor blade airloads and the resulting rotor blade motions and bending moments, rotor shaft loads and moments, and fuselage vibration. The voluminous output of this extensive instrumentation was processed by a fully automated data system which is described in this volume. Data were tape-recorded in sequenced-multiplexed, frequency-modulated (FM) form during flight testing. The FM signals were discriminated to analog form and were digitized by using a high-speed analog-to-digital converter. Digital data were calibrated, corrected for temperature and load interactions, and harmonically analyzed by using a series of digital computer programs. Airloads pressure data were numerically integrated to determine instantaneous blade section lift and pitching moment and the lift and pitching moment of the entire rotor blade. Data were also prepared for other analyses. The data system also included various data checks which are discussed. Substantiating tests and analyses that were performed to ensure the proper operation of this system are also presented. Data output from this program is available on a computer tape (nine-track, IBM System 360) in fully identified form for utilization in further analyses.

FOREWORD

This report describes the development of the system that was used to process and analyze the data that were recorded during the Dynamic Airloads Program. The project was performed under Contract DA 44-177-AMC-124(T) through the period from June 1964 to July 1966. The reports covering the basic program consist of four volumes, of which this is Volume III. The remaining volumes are as follows:

Volume	I,	Instrumentation and In-Flight Recording System
Volume	II,	Calibrations and Instrumented Component Testing
Volume	IV,	Summary and Evaluation of Results

An extension to this program to obtain data under extreme operating conditions for subsequent analysis will produce an additional volume of this report, as follows:

Volume	V,	Investigation of Blade Stall Conditions

The project was conducted under the technical cognizance of William T. Alexander, Jr., of the Aeromechanics Division of USAAVLABS. The author of this report is John W. Obbard, Engineer-Data Systems Analyst, Structures Technology. The program was executed under the direction of Richard R. Pruyn, Dynamic Airloads Project Engineer for The Boeing Company, Vertol Division.

CONTENTS

CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS

TABLES

SYMBOLS

a_k	corrected cosine coefficient of k^{th} harmonic of a Fourier series
$a_k(L)$	k^{th} corrected cosine coefficient of lag angle as used in Interaction Load Equivalents Program, degrees
a_{ku}	uncorrected cosine coefficient of k^{th} harmonic of a Fourier series
A/D	analog-to-digital signal conversion
A_o	steady term (arithmetic mean)
b	number of blades per rotor
b_k	corrected sine coefficient of k^{th} harmonic of a Fourier series
$b_k(L)$	k^{th} corrected sine coefficient of lag angle as used in Interaction Load Equivalents Program, degrees
b_{ku}	uncorrected sine coefficient of k^{th} harmonic of a Fourier series
BCD	binary coded digital
BIAS	bias (sixth calibration step), counts
BL	baseline (third calibration step), counts
BW	40-percent bandwidth (second calibration step), counts
C	blade chord, inches - Centigrade, degrees
C_1, C_2, etc.	blade chordwise locations, inches from leading edge
CAS	calibrated indicated airspeed, knots
C_R	pitch moment reference position, inches from leading edge

SYMBOLS

C_{TBL}	baseline thrust coefficient
C_{TI}	initial thrust coefficient
C_{TW}/σ	rotor thrust-coefficient-to-solidity ratio, based on run gross weight
dx	increment of x
D	distance between rotor hub centers, feet
EDP	electronic data processing
EQUIV	calibration equivalent from instrumentation card, engineering units
EZ	electrical zero (fourth calibration step), counts
$f(x_k)$	value of function being integrated at chord position x in Appendix III
F_A	actual loads
F_M	measured loads (not necessarily actual loads due to instrumentation interactions)
F_x	force in the x direction such as blade radial tension, pounds
F_y	force in the y direction such as blade chordwise shear, pounds
F_z	force in the z direction such as blade flapwise shear, pounds
$F_z(13)$	flapwise shear at the 13-percent radius, pounds
GW_{BL}	gross weight at V_{BL}, pounds
GW_I	gross weight at V_I, pounds
H_{D1}	density altitude (from flight card data), feet

SYMBOLS

H_{D2}	density altitude (from digitized data), feet
H_p	pressure altitude, feet
I	station designation (from reference station), inches
IAS	indicated airspeed, knots
IBSORT	IBM data sorting program
INF	suffix indicating in-flight calibration data
Interrupt-30	computer function initiation signal used in this program to indicate rotor azimuth position
Interrupt-40	computer function initiation signal used in this program to indicate a calibration step
IRIG	interrange instrumentation group - in this report, term refers to subcarrier oscillator frequency bands
k	harmonic number
K_f	correction applied when analyzing frequency-sensitive data
K_L	correction for nonlinearity at value of V_{ZS}
K_S	temperature sensitivity constant, units per unit value per degree C
K_Z	zero-shift constant, units per degree C
L	total lift per blade, pounds
ms	milliseconds
M_c	measured airload pitching moment per unit span at the root cutout
M_f	root aerodynamic flap moment, inch-pounds
MODAYR	contraction for month-day-year

SYMBOLS

M_p	pitch moment per blade, inch-pounds
MVCO	millivolt-controlled oscillator
M_x	moment in x direction such as blade torsion moment, inch-pounds
M_y	moment in y direction such as blade flapwise bending moment, inch-pounds
M_z	moment in z direction such as blade chordwise bending moment, inch-pounds
$M_z(L)$	chordwise bending moment at the lag hinge, inch-pounds
n	number of ordinates
NBFM	narrow-band frequency modulation
OAT	outside air temperature, degrees C
P_1, P_2, etc.	differential blade pressures, pounds per square inch
P_L	absolute pressure on lower blade surface, pounds per square inch
PRE	suffix indicating preflight calibration data
P_U	absolute pressure on upper blade surface, pounds per square inch
R	rotor blade tip span, inches
$\bar{R}$	blade flap moment arm, inches or feet as applicable
R_c	blade span at start of airfoil, inches
Rcal	resistance calibration (fifth calibration step), counts
RCG	run center of gravity, inches

SYMBOLS

RGW	run gross weight, pounds
R(I)	blade span station, inches
R_k	harmonic resultant
R(L)	percent of blade span at lag hinge
RPM	rotor rpm
RPM_{BL}	rotor rpm at V_{BL}
RPM_I	rotor rpm at V_I
S_A	station of aft rotor, inches
S_F	station of forward rotor, inches
S_{FL}	fuel load cg station, inches
S_{NOM}	nominal cg station, inches
t	ambient temperature during run, degrees C
t_o	ambient temperature during circuit balance, degrees C
T_A	approximate aft rotor thrust, pounds
TAS_1	true airspeed (from flight card data), knots
TAS_2	true airspeed (from digitized data), knots
T_F	approximate forward rotor thrust, pounds
TFR	total fuel remaining (if positive) or total fuel used (if negative), pounds
TOCG	takeoff center of gravity, inches
TOFL	takeoff fuel load, pounds
TOGW	takeoff gross weight, pounds
V_{BL}	value shifted to baseline

SYMBOLS

V_C	corrected digitized value, counts
VCO	voltage-controlled oscillator center frequency (first calibration step), counts
V_E	uncorrected real engineering value, pounds per square inch, pounds, etc., as applicable
$V_{E_{CORR}}$	corrected real engineering value, pounds per square inch, pounds, etc., as applicable
V_I	indicated or uncorrected value in Correction Program
V_R	uncorrected digitized value, counts
V_Z	value corrected for zero drift in Correction Program
V_{ZS}	value corrected for temperature-induced zero and sensitivity shifts in Correction Program
V_{ZSL}	value corrected for temperature-induced zero and sensitivity shifts and for nonlinearity in Correction Program
x_k	chordwise locations in Appendix III
X_o	zero reference level from instrumentation card, engineering units
X_i	0°, ΔX, $2\Delta X$, ...$(n-1)\Delta X$, where $\Delta X = 360/n$
Y	function of V_E
Y_1	an ordinate at ΔX
Y_i	ordinate at X_i
Y_n	ordinates
$\Delta\bar{C}_N$	pitch moment arm, inches
ΔL	lift per unit span, pounds

SYMBOLS

ΔL_N	increment of lift per unit span produced by the blade section between the rearmost pressure transducer and the trailing edge, pounds per inch
ΔM	pitch moment arm per unit span, inches
$\Delta M(I)$	total mass between station 3 and station I, slugs
ΔP	differential pressure, pounds per square inch
ΔR	an increment of the blade radius, feet
ΔX	increment of phase, degrees
θ_k	system phase lag, degrees
θ_P	parameter phase lag, degrees
θ_R	rotor azimuth indication phase lag, degrees
μ'	rotor advance ratio
π	3.1416
ρ	density of air, slugs per cubic foot
ρ_{BL}	density of air at V_{BL}, slugs per cubic foot
ρ_I	density of air at V_I, slugs per cubic foot
$\frac{\rho}{\rho_o}$	air density ratio
σ	density ratio, degrees
Φ	corrected phase angle, degrees
Φ_k	corrected phase angle of k^{th} harmonic, degrees
Φ_ψ	phase angle of rotor azimuth (Interrupt-30 signal), degrees
Ω	rotor rpm
1/rev., 3/rev., etc.	one-per-revolution, three-per-revolution, etc.

INTRODUCTION

This report, which is one of a series prepared under the Dynamic Airloads Program, Contract DA 44-177-AMC-124(T), describes the system used to process and analyze the data acquired during the flight test portion of the program. The system is based upon the use of an automatic, high-speed, analog-to-digital (A/D) converter and a large-capacity digital computer. This type of equipment is essential for processing the large volumes of data generated by a program of this magnitude. The principal effects of the use of automated data reduction equipment, as opposed to visual interpretation of oscillograms, were as follows:

1. There was a quantum increase in the volume of data processed. This resulted from the reduced cost per data point, which made it practical to use the sample rates that are required to analyze dynamic data.

2. Visibility of the data was lost, due to the elimination of the analysis of oscillograms. This effect was offset by providing sophisticated data-validity checks.

3. The high resolution of this equipment considerably improves the accuracy of data, leading to requirements for more sophisticated correction and analysis programs.

4. The increase in volume and complexity of data processing makes computer availability an important consideration.

These effects were anticipated, and since the sophistication and complexity of data processing made large, multipurpose computer programs difficult to write, the decision was made to provide a series of small, single-function data-processing computer programs. This decision was influenced by prevailing computer operations, since it is the practice that, when operational conflicts occur, short programs are run in preference to long programs. The concept of restricting each program to a single basic function also afforded flexibility within the data system. This flexibility not only permitted each program to perform several anticipated variations of its basic function, but also provided for the addition of further routines as needed.

The development of the data system was to some degree influenced by prior experience with semiautomatic systems. The cost of these manual reading-automatic recording systems, however, limited greatly the amount of digitized data prepared. As a result, the flexibility and general usefulness of these test programs were very limited. It was therefore decided to consider all programs written for the semiautomatic system as obsolete. This past experience demonstrated the requirement for completely identified and standardized inputs and the usefulness of numerous specialized computer programs as compared to one large general program.

In implementing the new data system, it was decided to provide the basic data calibration system with numerous options. The calibrated, harmonically analyzed, and corrected data were then to be the input into an array of analytical programs. Finally, a correlation program was provided to compare the output of the various analytical programs. This system placed emphasis on meeting minimum pretest requirements with provision for continuing long-term development.

THE DATA SYSTEM

It is the function of the Data System to read data from magnetic tapes, to accept manually recorded flight condition data, and to combine these readings with instrumentation descriptions and calibrations in a manner which will provide listed and plotted flight test data. This process involves discrimination to separate the FM recordings, utilization of the preflight and in-flight calibrations, and various data analyses. The hardware involved includes a high-speed analog-to-digital converter with a digital computer for control and a large data analysis computer. Analysis of data starts with calibrations and corrections for nonlinearity, temperature, and interaction loads, and then proceeds to harmonic analysis with phase and frequency corrections; finally some selected data are integrated, and in some instances the flight data are combined with theoretical data to prepare data coefficients. Data are listed, plotted, and prepared on a computer input tape for further analysis. This system is described in the following sections of this report.

The flow of data through the data system is illustrated in Figure 1. Data are combined and processed as soon as the flight test tape enters the ground station. First, certain signals from the tape are reproduced on an oscillogram so that record identification times can be identified. These intervals of data, called edit times, together with the manual flight recordings, flight and run identifications, and instrumentation organization and identification data, are input to the digitizing equipment, together with the flight test tape. This equipment provides a fully identified data tape which consists of samples of up to 40 signals, which are obtained at a prescribed sampling rate. Seven passes through the equipment are required to obtain all the data.

At this point in the system the data are not converted to engineering units. The digitized tapes are taken to the central computing center where they are input into an IBM 7044 computer, together with the calibration data and various calibration and analysis programs. Output from these programs is in the form of listings and automatic plots.

The calibration and analysis programs are arranged into two successive groups, each of which comprises a number of individual programs. All programs encountered up to and including the

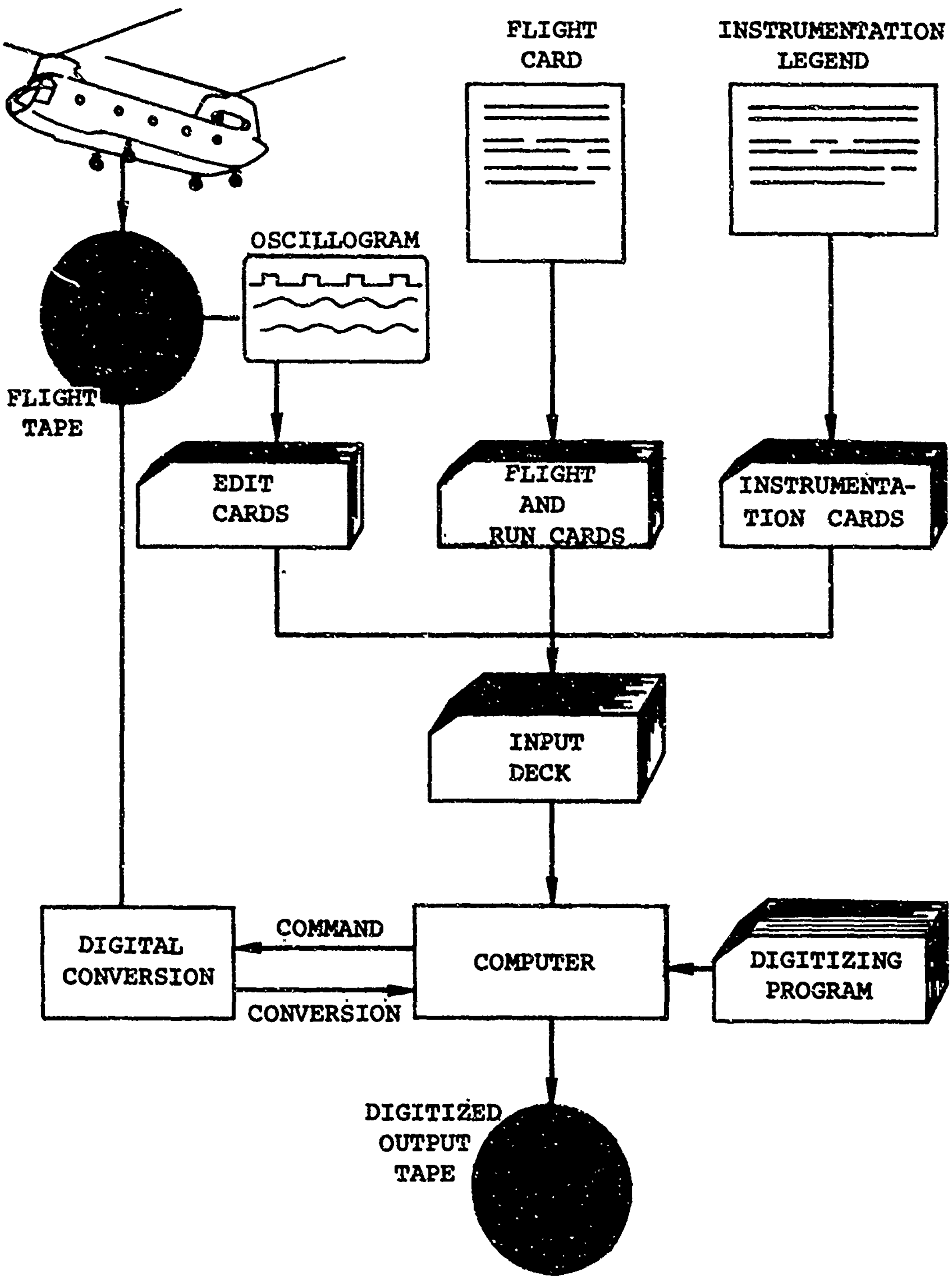


Figure 1. Data System Flow Diagram of Digitizing Process.

Interaction Corrections Program are collectively referred to as the Calibration Programs, even though some analysis and considerable checking are also performed. Following the Interaction Corrections Program, the data are input sequentially into the various analytical programs. Selected outputs from these several programs are then input together with detailed analytical and other inputs in the Comparisons Program.

The basic analysis performed during the calibration portion of the processing is a Fourier series analysis to determine the harmonic content of each waveform. This series is of the form

$$f(t) = A_o + \sum_{k=1}^{\infty} \left(a_{ku} \cos \frac{2k\pi t}{P} + b_{ku} \sin \frac{2k\pi t}{P} \right), \tag{1}$$

where the steady term is

$$A_o = \frac{1}{P} \int_o^P f(t)\,dt, \tag{2}$$

the cosine coefficient is

$$a_{ku} = \frac{2}{P} \int_o^P f(t) \cos \frac{2k\pi t}{P}\,dt, \tag{3}$$

and the sine coefficient is

$$b_{ku} = \frac{2}{P} \int_o^P f(t) \sin \frac{2k\pi t}{P}\,dt. \tag{4}$$

These terms (A_o, a_{ku}, b_{ku}) are then used as the basis for all further analyses.

FLIGHT TEST DATA RECORDING PROCEDURES

The characteristics of the data processing system were in part determined by data recording procedures. The latter included multiplexing, time sharing (sequencing), automatic calibrations, and the use of interrupt signals to control directly a computer function.

DATA MULTIPLEXING AND SEQUENCING

The requirements for the in-flight recording of approximately 237 signals on one 14-track magnetic tape recorder made multiplexing necessary. The standard interrange instrumentation group (IRIG) narrow-band frequency-modulation (NBFM) method was used. Low-level signals (0 to 20 millivolts) were conditioned to the NBFM signal using millivolt-controlled oscillators (MVCO); similarly, high-level signals (0 to 5 volts) were conditioned using voltage-controlled oscillators (VCO). These units were custom-built to a Boeing specification but did not differ appreciably from standard instruments.

It was also necessary to time-share rotor data by alternately recording signals from 1 rotor for 2 rotor cycles and by then switching and recording from the other rotor. During switching, 1 rotor cycle was lost. Thus, on a given run, forward rotor data were recorded on cycles 1, 5, 9, 13, and 17; and aft rotor data, on cycles 3, 7, 11, 15, and 19. The complete set of data for 5 rotor cycles required approximately 5 seconds of flight time.

PREFLIGHT AND IN-FLIGHT CALIBRATIONS

Calibrations, both preflight and in-flight, were recorded automatically. A 6-step preflight calibration (see Figure 2) was recorded before flight on both the forward and aft rotor data. Each step was held for 2 seconds, giving a 12-second calibration cycle. During each step an Interrupt-40 signal was given. This computer function initiation signal was used to indicate a calibration step. Upon receiving this signal, 5 samples of data would be read at 100-millisecond intervals. These samples were later averaged to provide a single value for each calibration step.

In a similar manner, each data record was followed by an automatic in-flight calibration, updating all circuitry for voltage-controlled oscillator (VCO) and amplifier drift. This

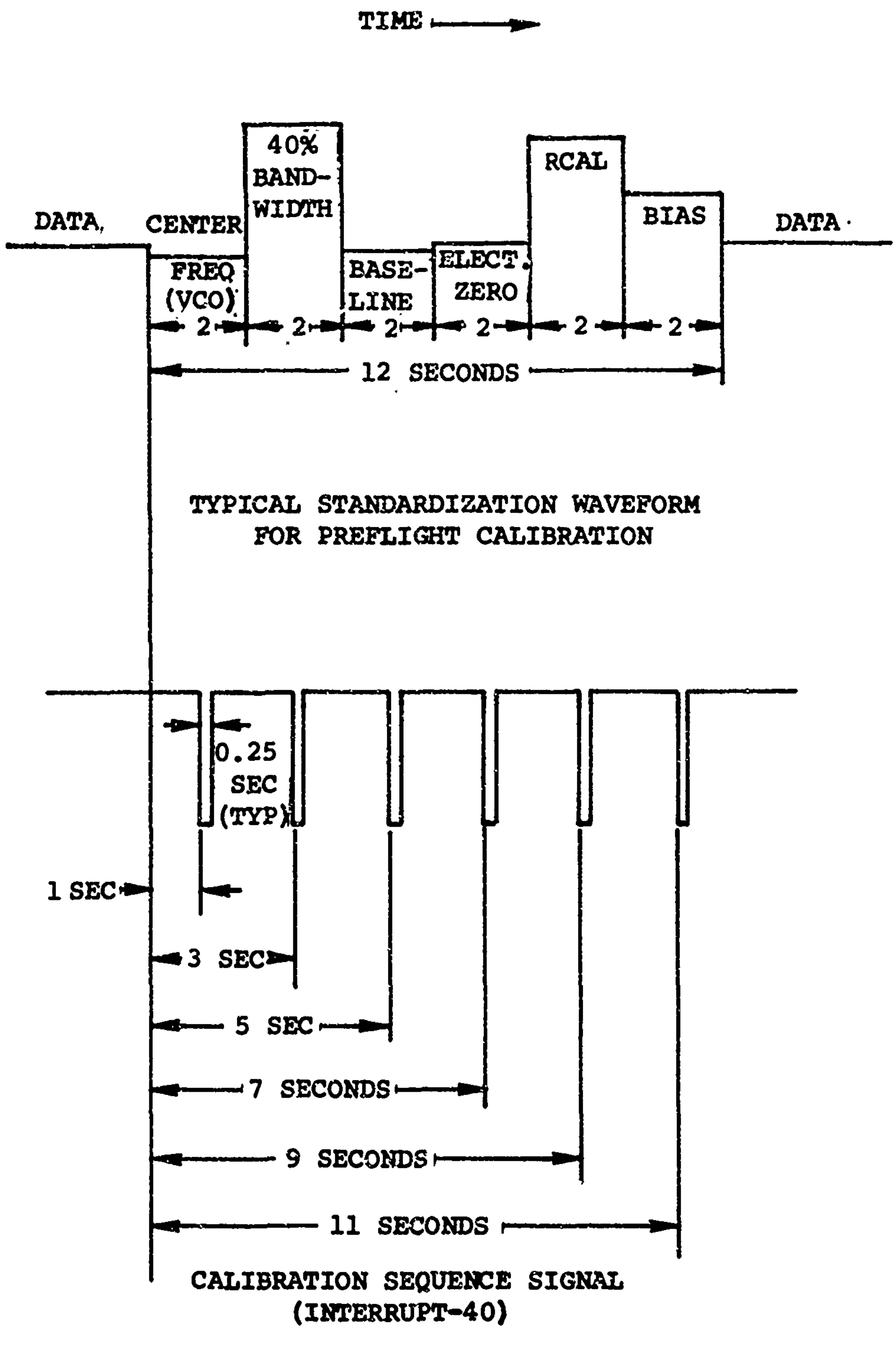


Figure 2. Representation of Automatic Calibration Signals Produced by Aircraft Instrumentation System.

calibration consisted of the first three preflight calibration steps.

In addition to the calibration signal, an Interrupt-30 signal was incorporated to indicate rotor azimuth position, and a sequence signal to indicate forward or aft rotor data.

Each airborne flight tape contained a prerecorded modulated carrier time code signal. This signal, when read from the oscillogram stripout and keypunched on edit cards, indicated those portions of the airborne tape to be digitized (see Figure 3). Ten edit cards were generated for each run - five for forward and five for aft rotor data.

FLIGHT CARD DATA

Prior to digitizing, flight, run, and instrumentation information obtained from flight card and instrumentation legends was incorporated by means of punched cards. Additional information as to the number of preflight calibrations was input on the first flight card. Because of the possibility of more than one preflight calibration on an airborne tape and the requirement for alternately recording forward and aft rotor data (sequencing), the Calibration Program required information as to the total number of preflight calibrations, the valid calibration for forward rotor data, and the valid calibration for aft rotor data.

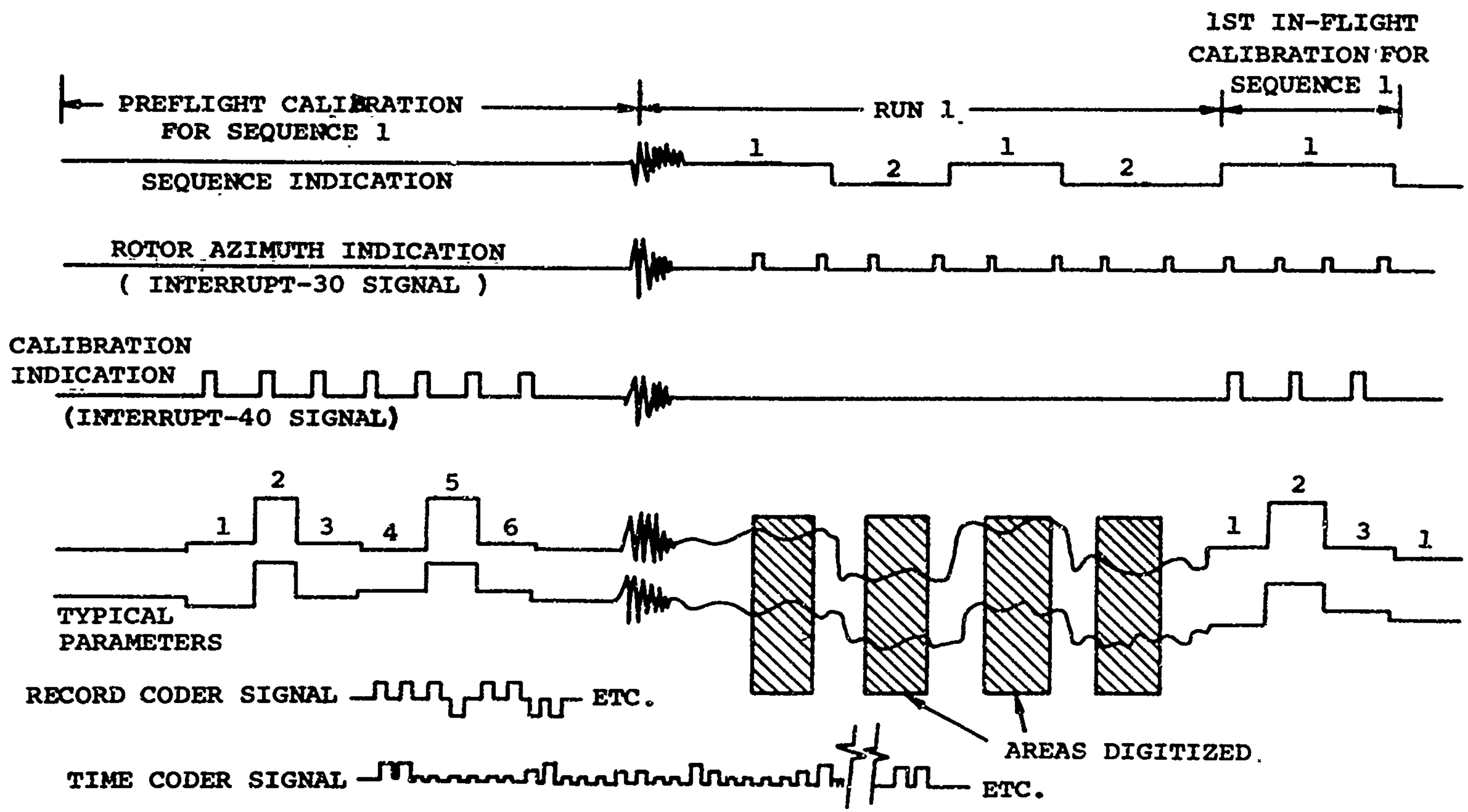


Figure 3. Selection of Flight Data from Oscillogram Before Digitizing.

ANALOG-TO-DIGITAL CONVERSION

Following a flight, the recorded data were reproduced to analog form in the flight test telemetry and data processing center (ground station). The NBFM data were discriminated by commercial pulse-averaging discriminators. Discriminators for IRIG bands 9 through 16 had 60-cycle-per-second low-pass constant-amplitude filters in the output. Discriminators for the lower bands were equipped with low-pass filters of frequencies consistent with the IRIG schedule (modulation index greater than 5). Three sets of 12 discriminators were available to enable 3 multiplexed composite signals to be simultaneously discriminated into a total of 36 analog signals. At the same time, functions such as time and the 1/rev. rotor azimuth reference pulse were reproduced from their separate FM tape recording tracks. These signals were input to the digitizing equipment as illustrated in the Figure 4 block diagram.

The analog data were converted to 11-bit digital words and recorded again on magnetic tape in a special format. This tape then became the data which were processed in the manner to be described later. The digitizing process was accomplished by a 40-channel high-level multiplexer gated to an 11-bit analog-to-digital converter. The analog signals were connected to the multiplex inputs through patch panels, and the addressing of the multiplexer was controlled by the computer in a sequence defined in the computer program. The sampling rate was also controlled by the computer in such a manner that each of the 36 analog channels was sampled at a rate at least 5 times greater than the highest frequency expected to be of interest in the reproduced signal.

DATA SOURCES AND IDENTIFICATION

The flight test instrumentation legend provided the primary source and identification information required for digitizing. This document listed the parameter source by tape track and IRIG band. From this a digitizing legend for each flight was generated by the ground station. This legend provided information as to the digital location of each analog signal.

For this program 12 IRIG multiplexing bands (bands 5 through 16) were employed. The number of parameters recorded (237) exceeded the 40-analog-channel limit of the digitizing equipment, necessitating multiple digitizing passes on each flight. These passes, identified by format numbers, each carried up to 3 tape

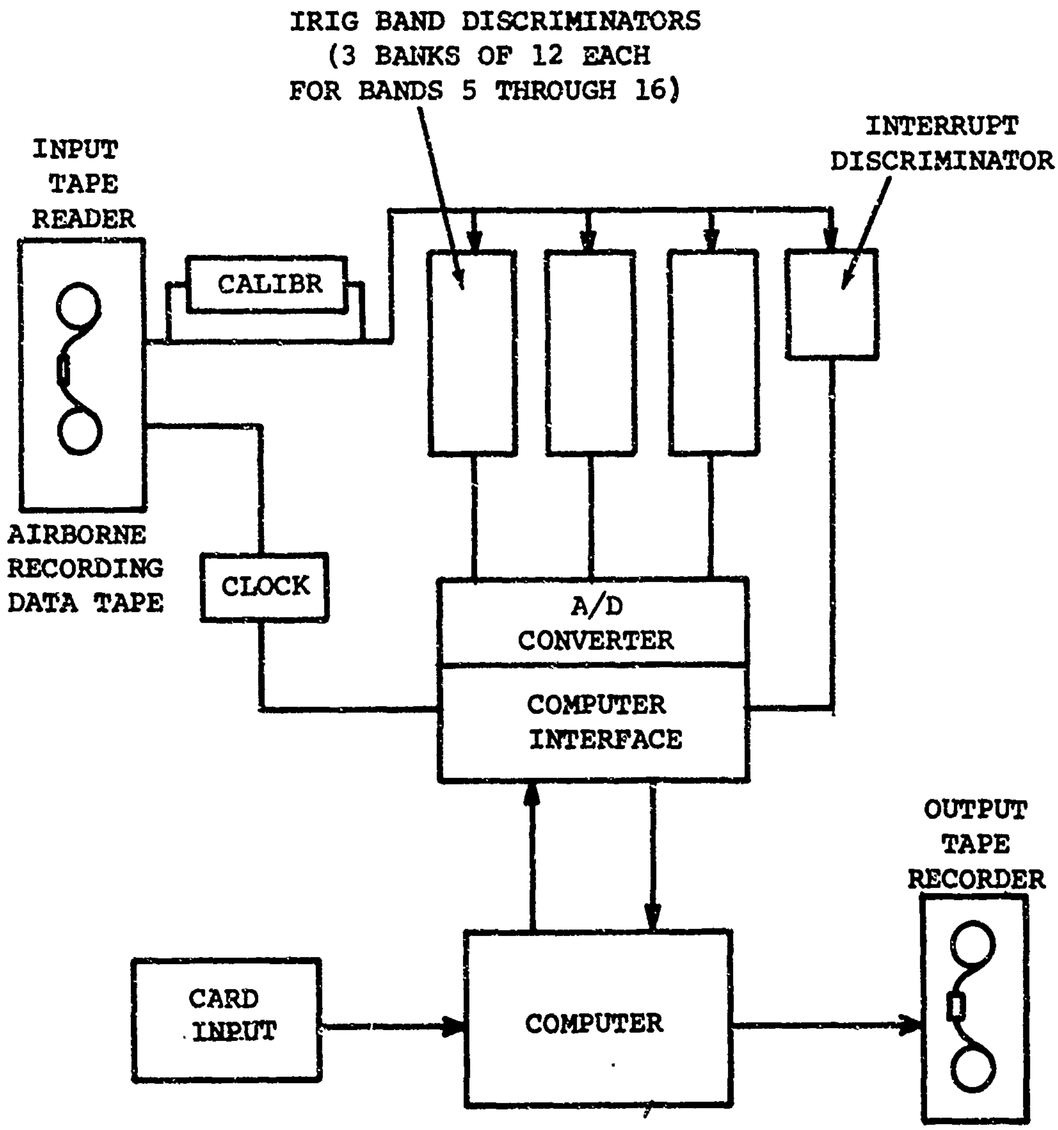


Figure 4. Block Diagram of Digitizing Equipment.

tracks of IRIG bands or 36 (3 x 12) parameters. Because the forward and aft rotor data were sequenced, there were never more than 5 formats per flight.

CONVERSION PROCEDURES

As a first step in the analog-to-digital conversion of data acquired on a test flight run, a portion of the data on the airborne magnetic tape was converted to analog readout for use in editing. This was accomplished by playing back the tape on a tape drive (Ampex FR-100C), through a bank of discriminators (Electro-Mechanical Research 189D), and onto an oscillograph (Consolidated Electrodynamics 5-119). The playback included the modulated carrier time code generator signal, a sequence indication signal, record coder, rotor azimuth (1/rev.) signal, and one tape track of representative parameters, as shown in Figure 3.

From this playback and from flight card and instrumentation legend information, a series of computer input cards was punched to supply flight, run, instrumentation, and edit information for the digital data. Briefly, these cards are as follows:

1. Flight card(s) which supplied flight information (takeoff gross weight, etc.) obtained from the aircraft flight card.

2. Run cards providing run information (run, airspeed, cyclic trim, etc.), obtained from the aircraft flight card; and run start time, obtained from the time code generator on the tape playback.

3. Instrumentation cards which supplied information pertinent to each digitized parameter and to sensitivity, location, units, etc.

4. Edit cards controlling the location, rate, and method of digitizing. One card was generated for each of the shaded areas shown in Figure 3.

Before digitizing, the discriminators were given a 3-point calibration check at their center frequency and lower and upper band edges. After calibration, the Edit and Format Program was put into machine memory from a storage tape and digitizing was

started. First, the flight, run, and instrumentation card data were written on the tape in BCD format for storage until required by a later program. Digitizing then commenced with the acquisition of one or more (in the case of sequencing) 6-step preflight calibrations. These were automatically digitized upon receipt of an Interrupt-40 signal by the computer, at which time 5 samples at 100-millisecond intervals were taken of each step. After preflight calibration, data were taken at each of the desired areas indicated by the edit cards. For this program, Sample Option Four was used, allowing data to be digitized at maximum sample rate (250 samples per second), starting with the first Interrupt-30 signal after the indicated start time. This option in the Edit and Format Program permitted the greatest possible accuracy and density in sampling. Because of alternate cycle sequencing, only one cycle was digitized in each sequence step (see Figure 3). On every run, each sequence cycled and was read 5 times.

After each run, an automatic 3-step in-flight calibration was taken to compensate for amplifier, VCO, and recording system drift while in flight. This was indicated by 3 Interrupt-40 signals; the calibration was digitized in the same manner. A flow diagram illustrating the digitizing process is shown in Figure 4.

Because the A/D equipment was limited to 40 analog channels, multiple digitizing passes (generally 4 to 5) were required to process a single flight tape. Each pass generated a separate output tape.

After digitizing and before sending the tape to the engineering center for further processing, the first portion of each output tape was printed out to check whether the BCD card data and preflight calibration were correct.

DIGITIZED OUTPUT TAPES

The beginning of each digitized output tape contained flight, run, and instrumentation card information written in BCD format. This was followed by digitized data in blocks of 20 samples each. Each sample was a single value for each parameter at a given instant in time, and consisted of time, 40 analog channel values, and 20 digital channel values.

Preflight and in-flight calibrations were written in the same format; they were differentiated from normal data by setting

the time value equal to unity. The end of a rotor cycle was indicated by a change in value of the 20th digital channel.

Sequence indication, as to whether forward or aft rotor data were being analyzed, was provided by a step function on the 40th analog channel. Forward rotor data (sequence 1) were indicated by any value greater than 1000 counts, and aft rotor data by any value less than -1000 counts.

PROCESSING OF DIGITAL DATA

After digitizing, the data were reduced and analyzed on the large digital computers at the engineering center. Because of the amount of data and the complexity of analysis, processing was divided into two sections, with each section in turn divided into a number of computer programs. Each program performed a given function or functions, and output a data tape for use in the succeeding program. All programs in each section were run as a single operation.

To derive full benefit from a multiprogram system, a standard format was employed on all output data tapes so that programs could be run in any desired logical order. The need for efficiently and rapidly checking large volumes of data was met with a Checking Program which compared reduced values with predicted airspeed-load envelopes.

IDENTIFICATION OF DATA DURING PROCESSING

A standard format was employed for all data records. With the exception of the output of programs such as Listing and Check, which generated only listing tapes, input and output for all programs were in the form of data tapes which followed this standard format. The format consisted of a 44-word header of flight, run, and parameter information, followed by varying numbers of data words. Every record carried its own identification as to the type of data and the generating program. This made each record complete in itself and therefore usable in any suitable program. It also enabled programs to be run in any desired logical order.

At the outset of a computerized test program, the data processing requirements are analyzed and the required computer programs set up in the desired order to form a data path for the test program. The data path then runs as a single job (i.e., program), unless it is desired to incorporate an interim stop point to check data before proceeding with the computation. When running, all operator instructions are generated by the programs, and no special instruction is required to run a path.

In writing the programs for the dynamic airloads study, the use of codes was expanded in order to provide further flexibility and to allow for increasingly sophisticated analysis. A code is a numerical designation of a physical description. For example, instead of describing a maneuver as "right sideward

flight", it is much easier to keypunch and operate on a maneuver code of "04". In this project, six different sets of code designations were used, as follows:

1. Data Code - A 4-digit integer number used to identify a given measurement on an aircraft. Generally, the first digit describes the type of measurement (stress, pressure, etc.); the remaining 3 digits, the location of the measurement.

2. Parameter Identification - A 13-digit alphanumeric designation used to identify a given measurement on an aircraft. It complements the above data code and, in essence, is a "readable" data code for use on listings and plots.

3. Type-of-Data Code - A 2-digit integer code used to identify a given type of data. For example, Type-of-Data Code 41 identifies forward blade chord shear gages. This code is used extensively in analysis programs where different types of data must be used in an analysis.

4. Maneuver - A 2-digit integer code used to identify an aircraft maneuver during a test run.

5. Phase - A 2-digit integer number used to identify interrange instrumentation group (IRIG) band and recording path of a parameter. This code is used in the Harmonic Analysis Program (Vertol Division designation M43) to identify the applicable phase-correction curve when correcting harmonic coefficients for phase error induced by the recording system. When the Harmonic Analysis Program is completed, the code serves no useful purpose and is dropped from the data tape.

6. Control Words - Nine single-digit control words are available for input on each run. These words permit differential analysis by run number. In the programs of this study, only the first two of these words affect data. Word 1 indicates the number of harmonics output from the Harmonic Analysis Program (M43) in tens; word 2 denotes the number of harmonics output from the same program in units.

A list of the codes used in this program is given in Appendix I.

DATA PROCESSING OPERATIONS

Upon their arrival at the engineering center, the digital tapes were logged in and set up for processing on an IBM 7044 computer. Because of the complexity of analysis in this program, an interim stop point to check data was incorporated and the data path was run as two separate jobs (see Figures 5 and 6).

The first program in the path, the Primary Load Calibration Program (M40), put digitized data in format and converted it from counts to real engineering units, using the BCD card input on the front of the digitized tape and the digitized preflight and in-flight calibrations. In addition, this program calculated true airspeed and density altitude and made certain corrections to the raw data.

Output from this first program consisted of a data tape of records in the standard format described in the introduction. For ease in handling, the records on this tape were then sorted into data code order using an IBM sort program (IBSORT). Data code order is that order in which all data from a given data code (parameter) are blocked together.

After sorting, the data tape went into the Averaging Program (M31), where the 5 cycles digitized on each run were averaged to obtain a single cycle for each run. The data tape from this program then went into the Correction Program (M51), where the data from the blade pressure transducers were corrected for nonlinear output, sensitivity, and zero-shift changes caused by temperature change.

Up to this point, each record consisted of the standard 44-word header followed by approximately 65 corrected ordinates from each rotor cycle. These data were now put into the Harmonic Analysis Program (M43), and the indicated waveform was broken down into a steady term (arithmetic mean) and into components of the first 12 harmonics. From this point on through the data paths, all data were treated as harmonic components. At this point, the data were corrected for phase shift and frequency sensitivity, based on parameter and record path as shown in Figures 7, 8, 9, and 10; and calculations were made to determine rotor advance ratio (μ'), forward and aft rotor thrust-coefficient-to-density ratio (C_{TW}/σ), run gross weight (RGW), and run center of gravity (RCG).

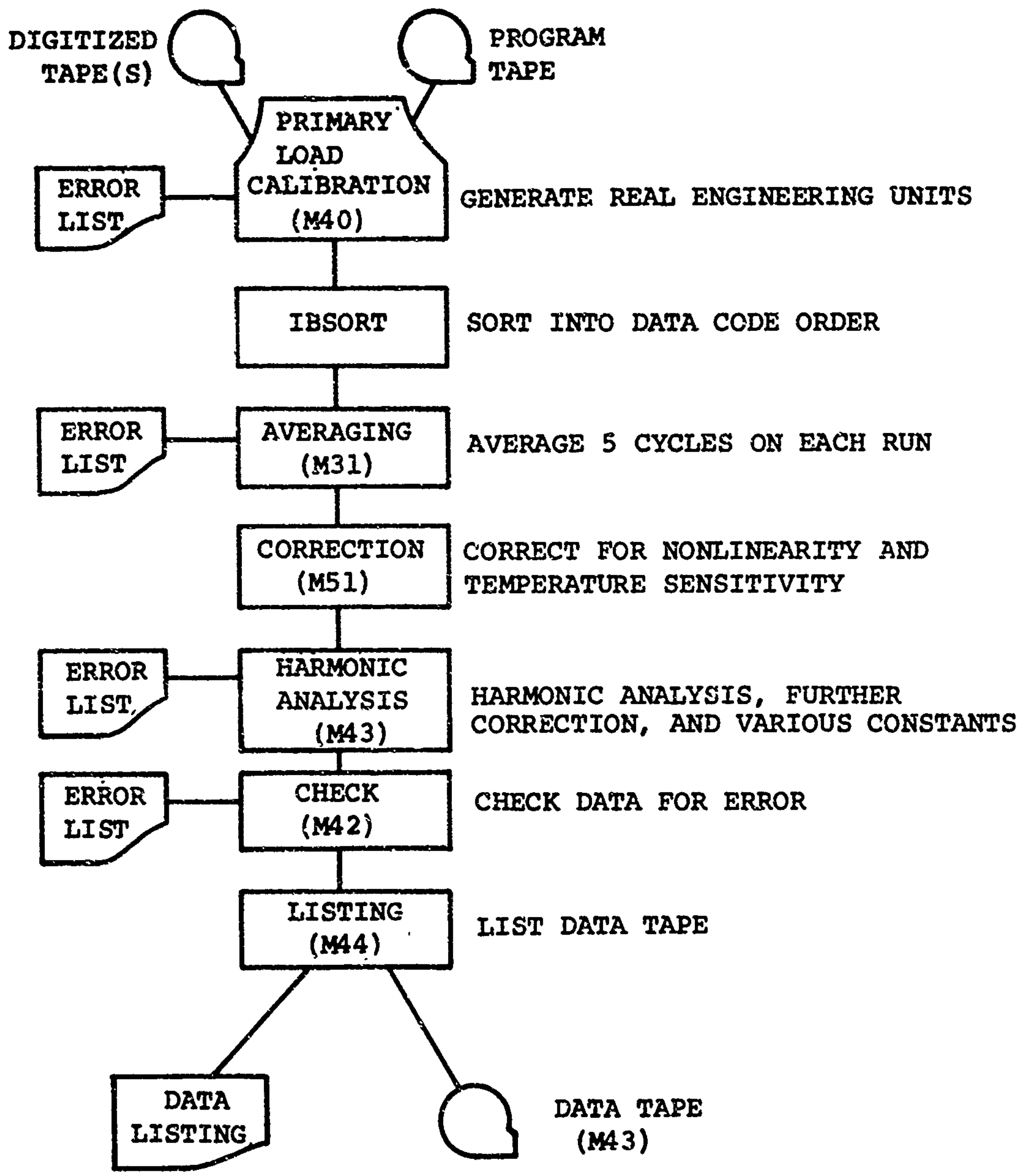


Figure 5. Initial Phase of Computer Processing of Dynamic Airloads Data.

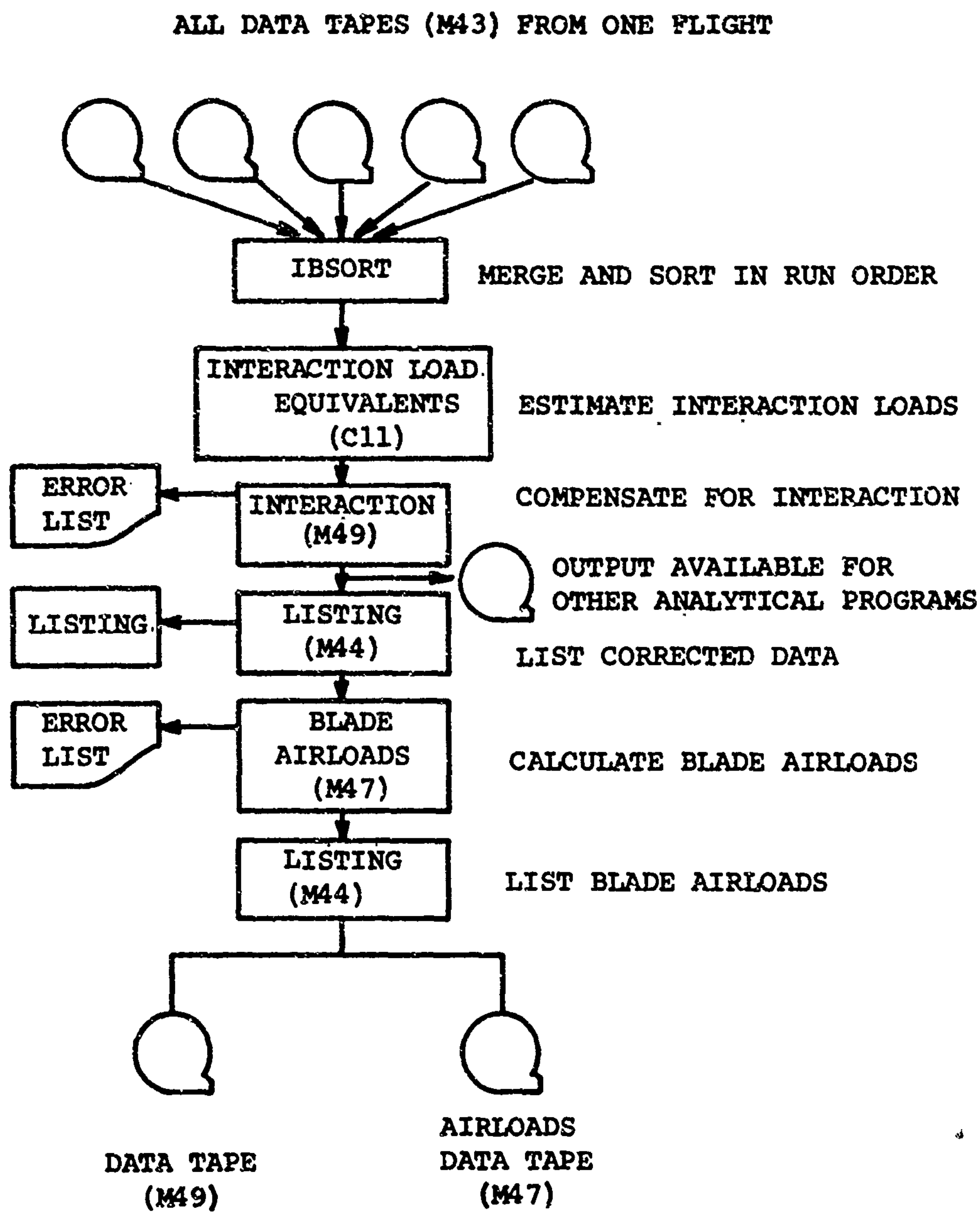


Figure 6. Second Phase of Computer Processing of Dynamic Airloads Data.

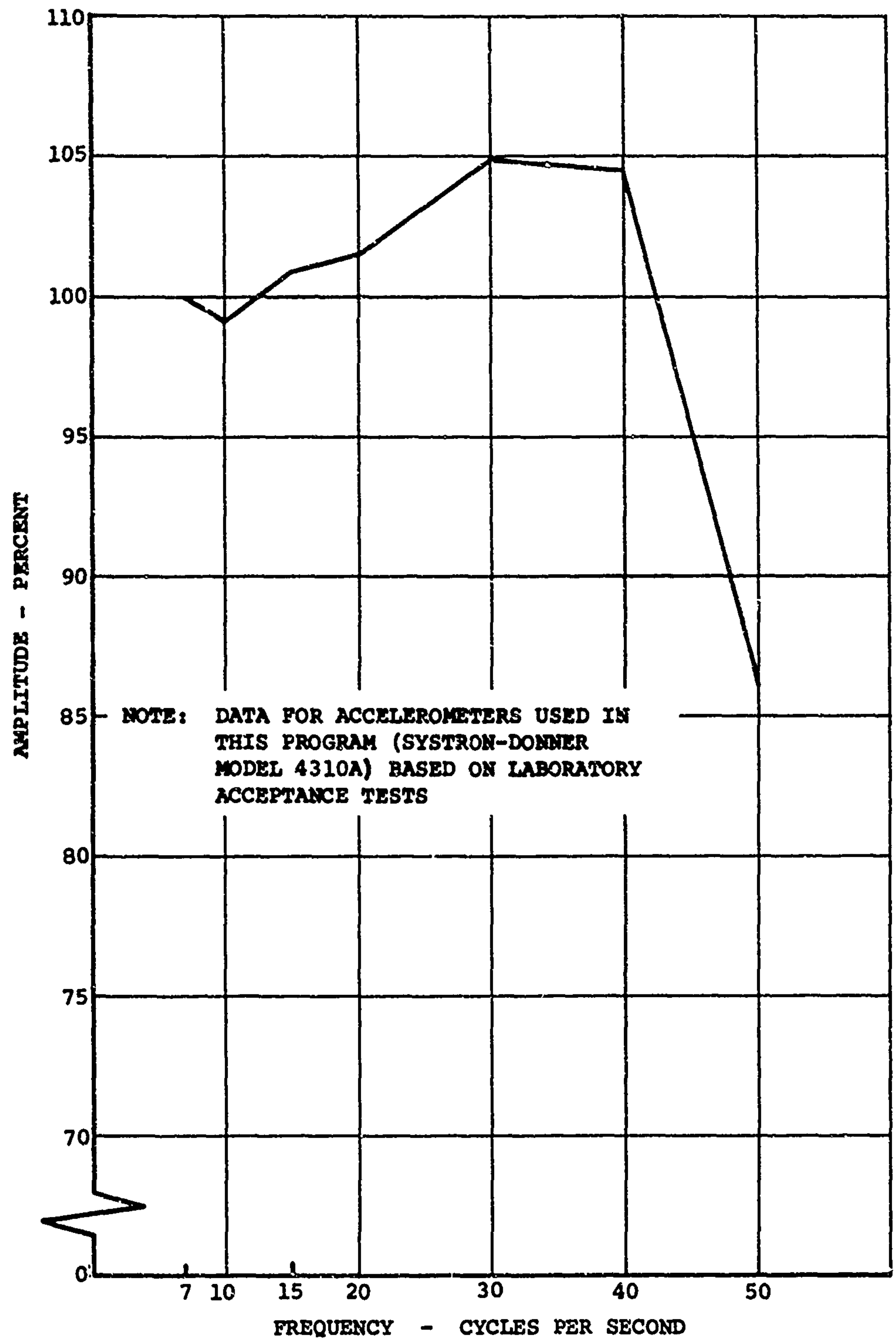


Figure 7. Frequency Sensitivity of Accelerometer.

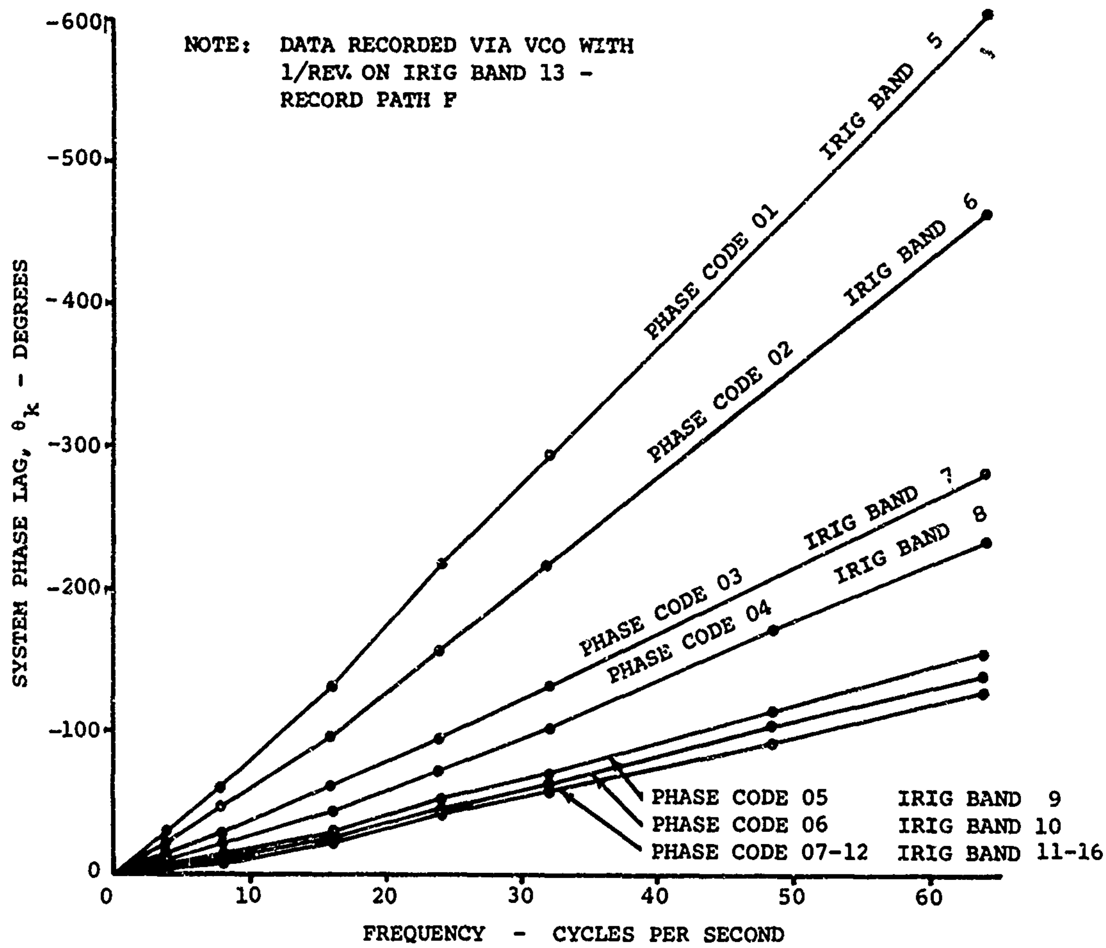


Figure 8. Phase Correction Curves for Recording System Lag - Strain Gage Data.

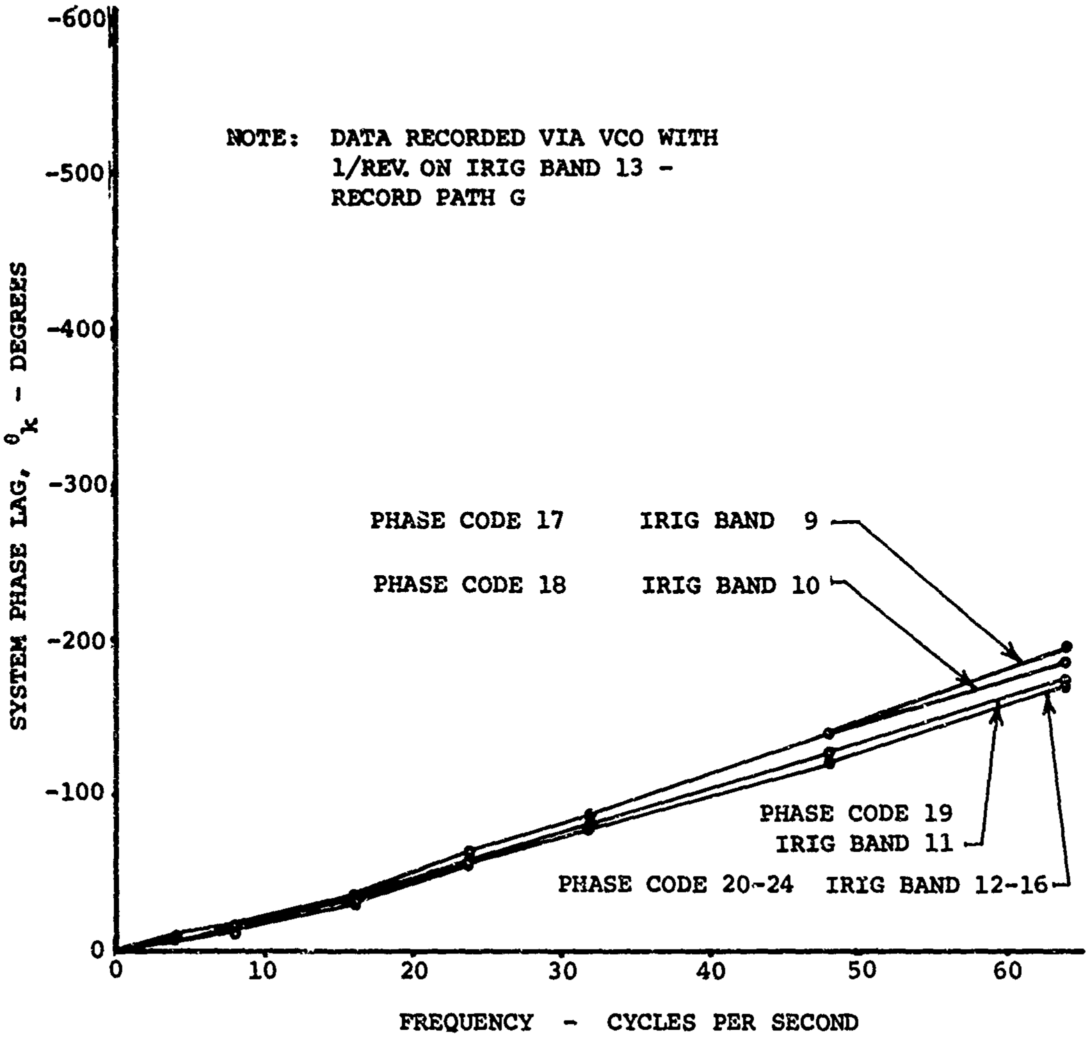


Figure 9. Phase Correction Curves for Recording System Lag - Blade Pressure Data.

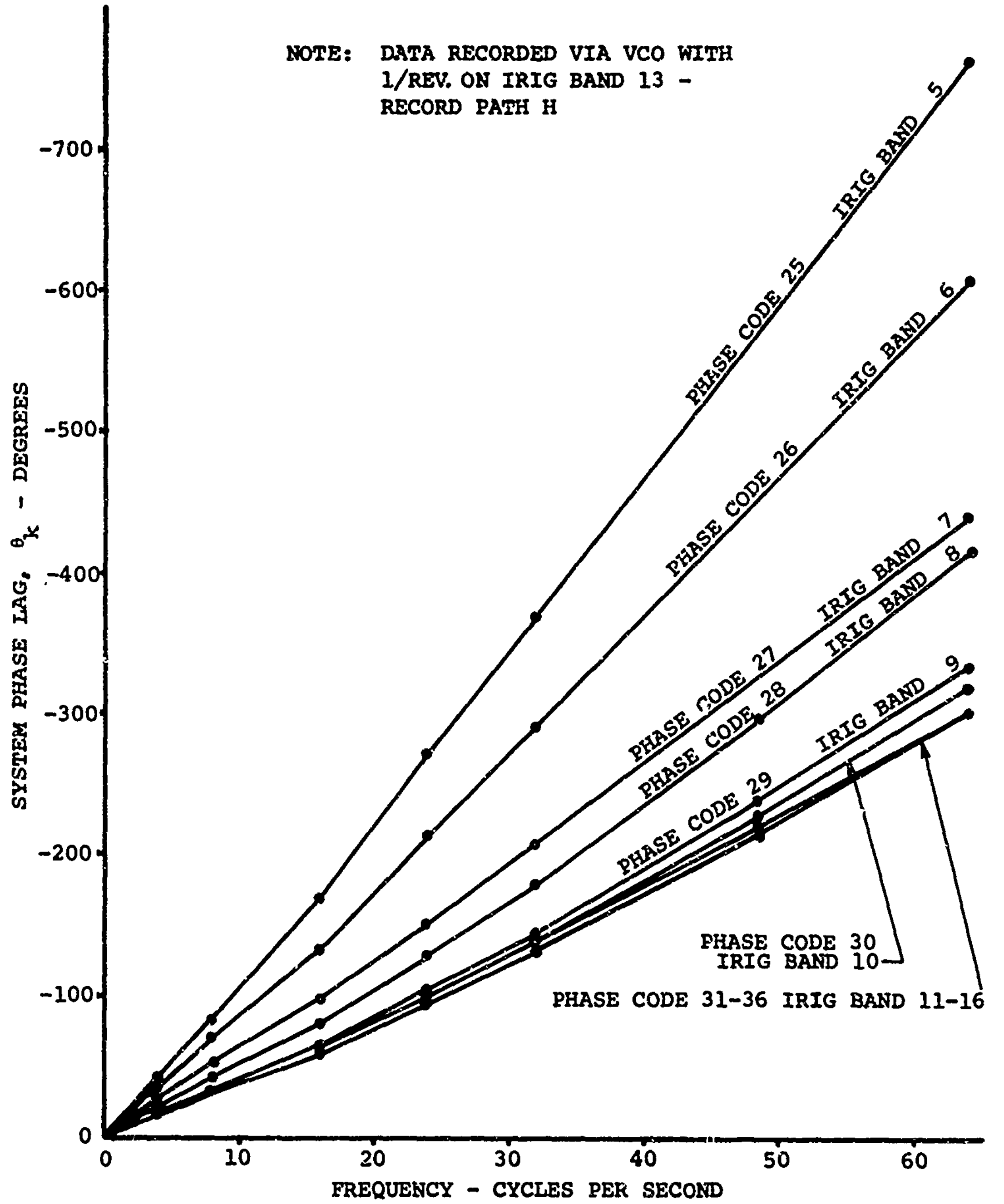


Figure 10. Phase Correction Curves for Recording System Lag - Accelerometer Data.

Following harmonic analysis, the reduced data were checked for error by the Check Program (M42), in which the steady term and one designated harmonic of each parameter were compared with a predicted airspeed-value envelope.

The method employed in this program was based on the fact that most test data vary in a predictable fashion with airspeed, as plotted in Figure 11. To check for values that fall outside the scatter band of Figure 11, an envelope was constructed around the plot as shown in Figure 12.

Using simple interpolation, the check program could now identify and print out any values falling outside the envelope. Two envelopes were available for each parameter checked, one for a steady term and one for an alternating term. When checking harmonically analyzed data, as generated in the Dynamic Airloads Program, the alternating term could be defined as any major harmonic component.

Note in Figure 12 that a portion of the scatter between 0 and N is not enveloped, but is labeled TRANSITION. In this area, helicopter data scatter might be so great as to be unsuitable for enveloping.

Still seeking to improve analysis, investigators noted that much data varied predictably, not only with airspeed, but also with the thrust-coefficient-to-density ratio (C_{TW}/σ) and with the square of the rotor advance ratio $(\mu')^2$. It was therefore decided that, when desired, the program would use these terms to shift the values of any desired parameter to a baseline value before interpolation. For example, the point marked A, outside the envelope in Figure 12, might be shifted to A' before interpolation. This baseline might be any set of gross-weight, center-of-gravity, altitude, and rotor-rpm conditions for which there existed enough data to construct an envelope.

This program served the double purpose not only of detecting error, but also of giving immediate warning of unexpected data values in a test, since data outside an envelope are not necessarily in error.

Finally, the data were listed using the Listing Program (M44), and the data tape was preserved for further processing. Each digitized tape (that is, each pass) was run individually, and all output tapes were saved for the second phase of the data path.

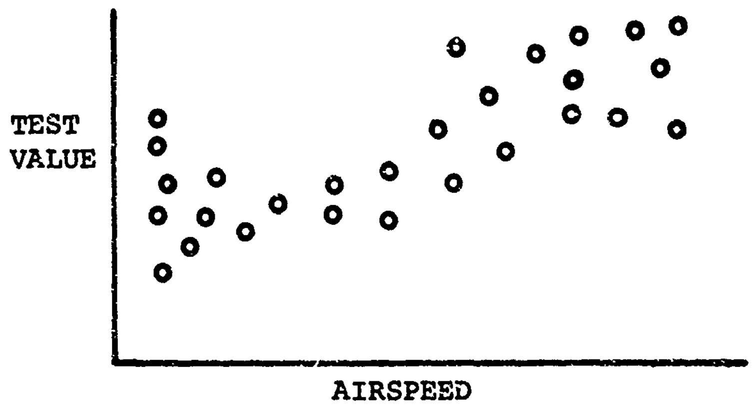


Figure 11. Typical Data Used to Generate Envelopes for General Check Program.

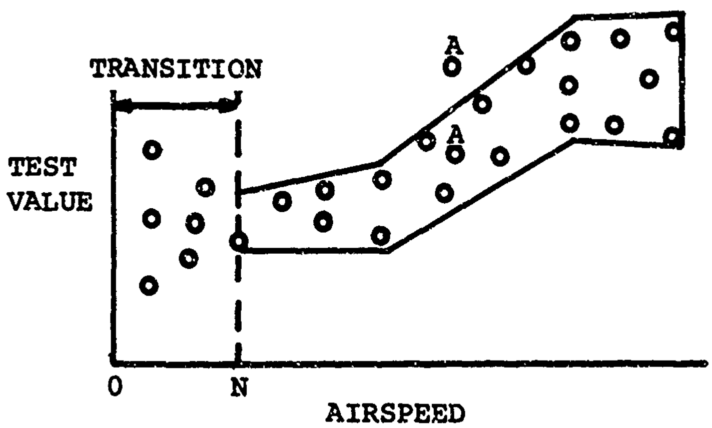


Figure 12. Definition of Data Check Envelope.

After the data were checked, the second phase of the data path was run as one job. First, the four or five Harmonic Analysis Program (M43) output tapes from each flight were merged by using the Sort Program (IBSORT); then the data were sorted into run order (see Figure 6). Run order is that order in which all the parameters from a given run are blocked together.

With the data merged and in run order, the Interaction Load Equivalents Program (C11) was used to generate theoretical blade loads at each gage location. Because of instrumentation limitations, it was not possible to have a complete force system (F_X, F_Y, F_Z, M_X, M_Y, and M_Z) at each gage location on the instrumented rotor blades, even though interaction coefficients for all forces were available on the existing gages. A program was therefore written to generate theoretical loads; existing gage values and known blade properties were used. This program generated complete data records in standard format for the missing gages, and produced them, along with existing records, on a data tape. The calculated data records were identified by a type-of-data code exactly 100 higher than those for actual data.

With a complete force system for each gage location, the Interaction Program (M49) was then used to correct rotor shaft and blade strain gages for interaction by matrix solution. In this program there were 12 force systems on each instrumented rotor blade and 1 on each shaft, making a total of 26 solutions on each run. Because of the method of calibration employed in the program, no matrix inversion was required, and each force system was solved by direct solution.

The corrected data were listed, to check for error, and then put into a Blade Airload Program (M47) which analyzed the blade pressure gages to determine lift per unit span, pitch moment per unit span, lift per span, etc. See Appendix III for a comparison of the Trapezoidal Rule numerical integration method used in M47 with the Legendre-Gauss method. After calculation, the data were listed by use of the Listing Program (M44).

After checking for error, the M49 output tapes from each flight were in turn merged and sorted in test-point order. The final high-density report listing and data tape were then generated. During this last manipulation, any erroneous data determined in prior checking were edited out of the data tapes by use of the Select and Edit Program (M05), as shown in Figure 13.

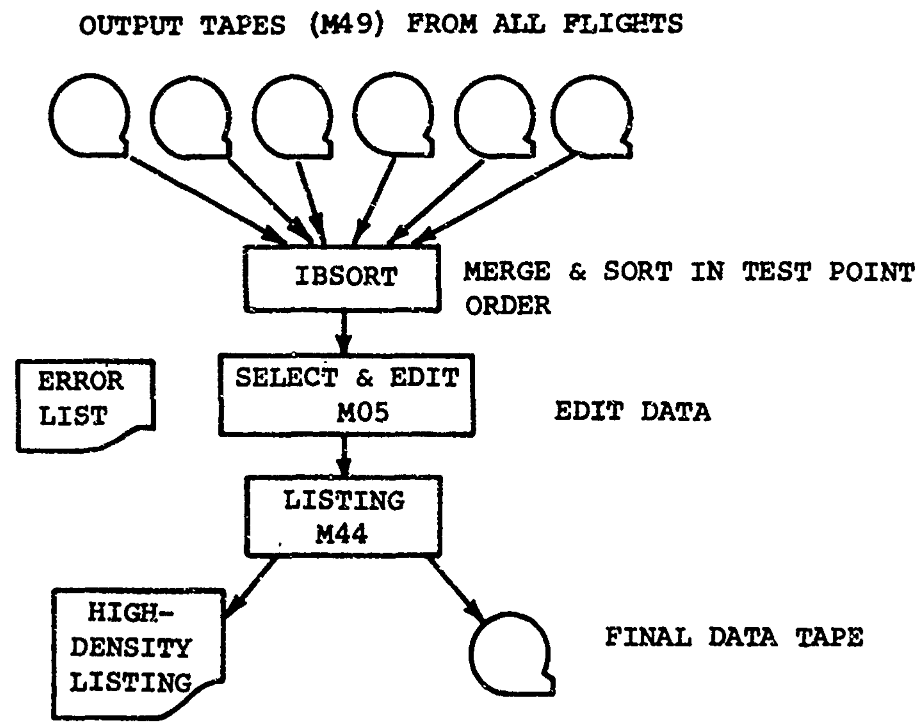


Figure 13. Final Merge, Sort, and Edit Data Path.

CALCULATIONS MADE BY COMPUTER PROGRAMS

The computer programs used to reduce and correct the flight data recorded in the Dynamic Airloads Program are described in the order in which they were used, as shown in Figures 5, 6, and 13.

Edit and Format Program (F02)

This program, used on the ground station digitizing computer (CDC 3100), controlled the A/D converter and put the data digitized into proper order. Program control was effected by a lead card indicating the number of channels, and by a series of edit cards indicating the run times which were digitized. A sample edit card is shown in Figure 14.

The edit and format program had six options of methods of sampling available as follows:

1. Sample from start time to stop time at maximum sampling rate (250 samples per second).

2. Sample from start time to stop time at R samples per second (R can vary between 1 and 250).

3. Sample from start time to stop time at one sample per pulse. The pulse referred to here and in the following options is the Interrupt-30 signal which will normally be triggered by the 1/rev. signal. Therefore one sample per pulse equals one sample per 1/rev.

4. Commence sampling at start time and sample for N pulses at maximum sampling rate.

5. Commence sampling at start time and sample for N pulses at R samples per second.

6. Commence sampling at start time and sample for N pulses at one sample per pulse.

The sample option, the sample rate (R), and the number of pulses (N) are indicated on each edit card.

When dynamic airloads data were digitized, option 4 was always used. With this option, the edit time was set slightly prior

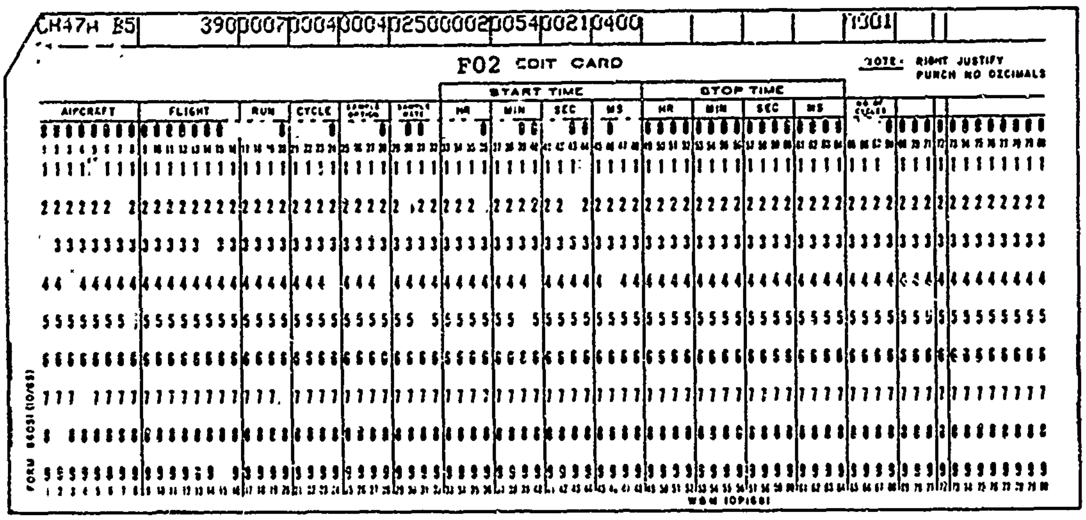


Figure 14. Sample Edit Card Input for Edit and Format Program (F02).

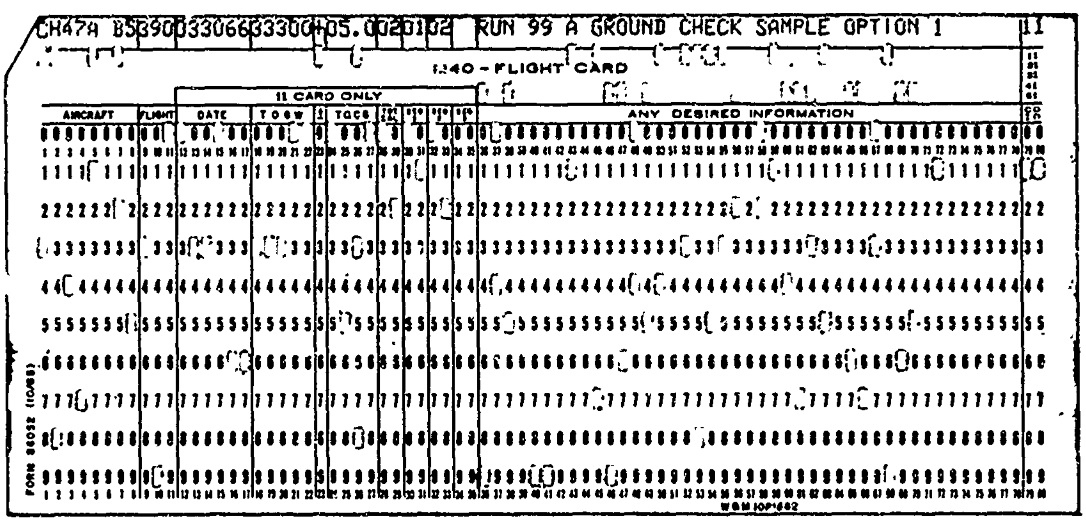


Figure 15. Sample Flight Card Input for Primary Load Calibration Program (M40).

to the rotor cycle it was desired to read, and digitizing was then triggered very accurately by the rotor azimuth signal which was fed directly into the computer as the Interrupt-30 signal. Because 1 rotor cycle was lost during sequencing (see Figure 3) and since every alternate rotor cycle was desired, 10 edit cards had to be generated (5 cycles x 2 sequences) for each run. On each card, N was set equal to one.

When digitizing, the flight, run, and parameter information required by the Primary Loads Calibration Program (M40) was first written on the digital tape in BCD format from punch card input (see Figures 15 through 17 for sample card inputs). The 6-step preflight calibrations were then digitized upon receipt of the Interrupt-40 signal (see Figure 3), with 5 samples being taken of each step at 100-millisecond intervals. After this, data were digitized, when indicated by edit card, at a rate of 250 samples per second. Depending upon rotor rpm, and hence time between rotor cycles, 62 to 73 digital readings were taken on each parameter.

After each run, an automatic 3-step in-flight calibration occurred to compensate for voltage-controlled oscillator and amplifier drift. This was digitized automatically in the same manner as preflight calibrations upon receipt of an Interrupt-40 signal.

Primary Loads Calibration Program (M40)

Upon completion of the Edit and Format Program, the digital tape and accompanying BCD information were then run through the Primary Loads Calibration Program (M40). This and all subsequent programs were run on an IBM 7044 computer at the engineering center. The primary function of this program was to convert the digital data from counts to real engineering units and to produce it in standard format. Up to this point, all data varied between +2047 and -2047 counts.

The program first identified and checked the card (BCD) input for error. To mitigate bad input, all card data were checked for concurrence of aircraft and flight identification;processing did not start until all these identifications matched. The card input data were then updated, if required, by correction cards. These M40 flight, run, and instrumentation cards, inserted after digitizing, were matched with and used to replace BCD card data. This permitted corrections to card data without redigitizing and also made it possible to override an

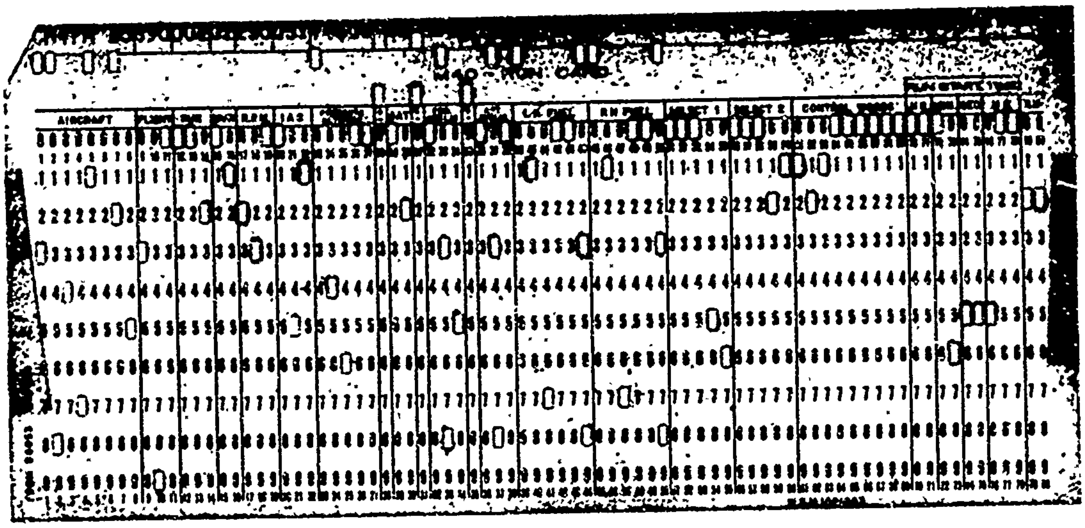


Figure 16. Sample Run Card Input for Primary Load Calibration Program (M40).

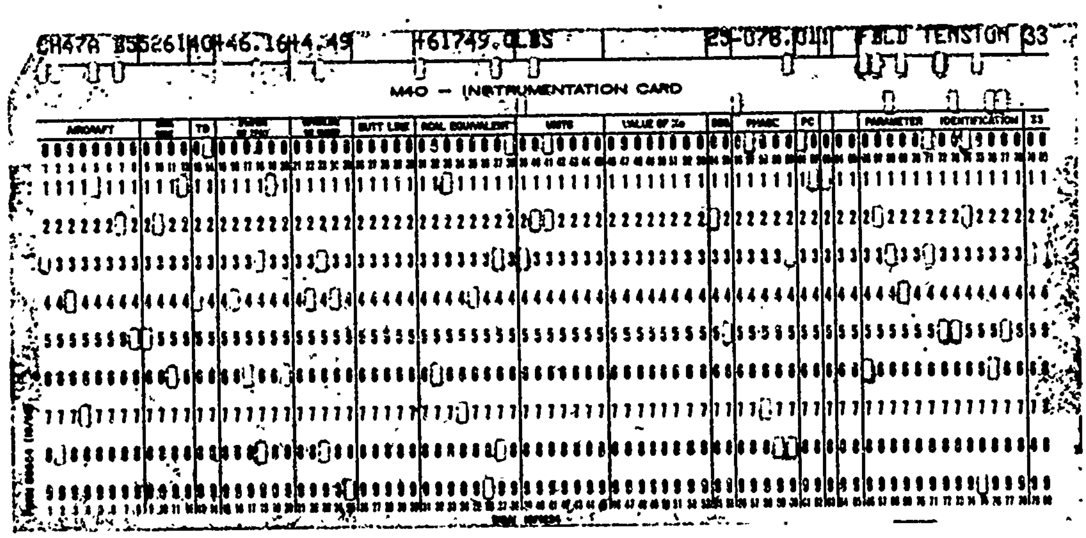


Figure 17. Sample Instrumentation Card Input for Primary Load Calibration Program (M40).

incorrect preflight calibration by similar card input.

Calculations then started, with equations applied individually to each digitized parameter. First the raw digitized value (V_R) in counts was corrected for VCO and amplifier drift by the equation

$$V_C = (V_R - BL_{INF}) \left(\frac{BW_{PRE} - VCO_{PRE}}{BW - VCO} \right), \qquad (5)$$

where
- V_C = corrected digitized value in counts
- V_R = raw digitized value in counts
- BL = baseline (third calibration step) in counts
- BW = 40-percent bandwidth (second calibration step) in counts
- VCO = voltage-controlled oscillator center frequency (first calibration step) in counts
- PRE = preflight calibration data
- INF = in-flight calibration data.

Data recorded before the first in-flight calibration were not digitized. However, for ground instrumentation check runs the following relation was provided:

$$V_C = V_R - BL_{PRE}. \qquad (6)$$

A real engineering value (V_E) was then calculated from the corrected engineering value by

$$V_E = \left[\frac{V_C - (BIAS - BL_{PRE})}{Rcal - EZ} \right] EQUIV + X_o, \qquad (7)$$

where
- V_E = uncorrected real engineering value in psi, lb, etc.
- BIAS = VCO bias input (sixth calibration step) in counts
- Rcal = signal during transducer standardization Rcal (fifth calibration step) in counts
- EZ = electrical zero, signal with no transducer excitation, (fourth calibration step) in counts
- EQUIV = calibration equivalent of transducer in engineering units (from instrumentation card)
- X_o = zero reference level in engineering units (from instrumentation card).

To permit matching of the instrumentation card with the digital channel, the digital sequence (channel) was indicated in columns 54 and 55 of the instrumentation card. With parameter sequencing employed, as in this program, the existence and number of sequences was indicated by the number of preflight calibrations in columns 28 through 35 of the flight card. When so indicated, the program checked column 63 of each instrumentation card for the sequence of the parameter, and checked analog channel 40 to determine the sequence of each sample. If the value here was greater than +1000 counts, the sample was sequence 1; if less than -1000 counts, the sample was sequence 2; and if between ±1000 counts, then it was sequence 3.

In this program there were a few parameters whose functions were nonlinear with the output signal. The M40 program could correct 10 such parameters by the use of lookup tables and the relation

$$V_{E_{CORR}} = Y, \qquad (8)$$

where
Y = constant found in the lookup tables for the value V_E.

Indicated airspeed and pressure altitude were corrected in this manner.

The Primary Loads Calibration Program also calculated true airspeed and density altitude, both from flight card data in the run card (TAS_1 and H_{D1}) and from digitized analog transducer data (TAS_2 and H_{D2}).

True airspeed was calculated from the function

$$TAS = \frac{CAS}{\sqrt{\frac{\rho}{\rho_0}}}, \qquad (9)$$

where
TAS = true airspeed in knots
CAS = calibrated airspeed in knots
$\frac{\rho}{\rho_0}$ = density ratio

and

$$\frac{\rho}{\rho_c} = \left(\frac{288.16}{OAT + 273.16}\right)\left[\left(1 - \frac{0.0019812\ Hp}{288.16}\right)^{5.25}\right]. \qquad (10)$$

Density altitude in feet is calculated as

$$H_{D2} = \frac{288.16}{0.0019812}\left[1 - \left(\frac{\rho}{\rho_0}\right)^{0.235}\right]. \qquad (11)$$

TAS_2 and H_{D2} were an average of all the digital samples in each run. When calculating TAS, the calibrated airspeed term (CAS) was obtained by addition of a position error correction to indicated airspeed (IAS).

Output from this program was a data tape in standard format similar to the standard output data record, with the exception that the data words (Word 45 and subsequent) were a series of 60 to 70 ordinates, and Words 39 through 41 contained phase-correction information dropped after the Harmonic Analysis Program was completed.

IBM Sort Program (IBSORT)

The M40 output tape records were in a modified run order. To get them into the data code order required by the Averaging Program (M31), the IBM 7044 Generalized Sorting System (IBSORT) was employed. Here IBSORT was set to put all records on a data tape in order of ascending identification data code, run, and cycle number within a run; this is known as data code order.

Averaging Program (M31)

When sorted into data code order, an Averaging Program (M31) was employed to average (take arithmetic mean of) the 5 cycles of each ordinate obtained from the 5 readings taken on each run. Averaging was done prior to harmonic analysis, to avoid excessive computer time in analysis of so large a volume of data.

As a check on the deviation between successive cycles, the largest absolute mean value of the ordinates of each parameter was checked to see if any of the samples that made up the mean deviated from it by more than 5 percent. If they did, an

error message was printed out giving data code, run, and percent deviation.

Correction Program (M51)

After averaging, the ordinates were corrected for transducer nonlinearity and temperature sensitivity by the Correction Program (M51). In the overall study program, only the Scientific Advances transducers used to measure blade airloads exhibited sufficient error to require correction.

The ordinates were first corrected for temperature-induced zero shift by

$$V_Z = V_E + K_Z\,(t - t_o), \qquad (12)$$

where
- V_Z = value corrected for zero drift
- K_Z = zero-shift constant in units per degree C
- t = ambient temperature during run in degrees C
- t_o = ambient temperature during circuit balance (i.e., preflight calibration). This was input on run cards as Select Word 2.

V_Z is then corrected for temperature-induced sensitivity change by

$$V_{ZS} = V_Z + V_Z K_S\,(t - t_o), \qquad (13)$$

where
- V_{ZS} = value corrected for temperature-induced zero and sensitivity shifts
- V_Z = value corrected for zero shift
- K_S = sensitivity shift constant in units per unit value per degree C.

Finally, V_{ZS} was corrected for nonlinearity by

$$V_{ZSL} = V_{ZS} + K_L\,, \qquad (14)$$

where
- V_{ZSL} = value corrected for temperature-induced zero and sensitivity shifts, and for nonlinearity
- K_L = correction for nonlinearity at V_{ZS}.

The values of K_Z, K_S, and K_L used in this program are listed in Appendix IV.

Harmonic Analysis Program (M43)

The corrected ordinates of each parameter were then analyzed to determine their harmonic components by use of a truncated Fourier series analysis.

First, each input record was checked for correct record identification and for the expected range in the number of ordinates; then the steady term (A_o) was calculated by

$$A_o = \frac{1}{n} \sum Y_n, \tag{15}$$

where

A_o = steady term (arithmetic mean)
n = number of ordinates
Y_n = ordinates.

The uncorrected cosine coefficients (a_{ku}) of the waveform were then calculated to the harmonic indicated in Control Words 1 and 2, using the equation

$$a_{ku} = \frac{2}{n} K_f \sum_{i=1}^{i=n} Y_i \cos k X_i, \tag{16}$$

where

a_{ku} = uncorrected cosine coefficient
k = harmonic number
n = number of ordinates
K_f = correction applied when analyzing frequency-sensitive data*
X_i = 0°, ΔX, $2\Delta X$, ...$(n-1)\Delta X$, where $\Delta X = 360/n$
Y_i = ordinate at X_i.

*The correction for frequency (K_f) was used for data from transducers which had a sensitivity that was a function of input frequency. This was handled as a lookup table of K_f and frequency, where the frequency was K(rotor rpm/60).

In cases where there was no lookup table, the value of K_f was automatically set equal to 1. In this program, the only parameters corrected for frequency were the outputs of the accelerometers used in measuring fuselage response. The response curve for these transducers is shown in Figure 7.

In a similar manner, the uncorrected sine coefficients (b_{ku}) were determined by

$$b_{ku} = \frac{2}{n} K \sum_{i=1}^{i=n} Y_i \sin k X_i. \tag{17}$$

From the uncorrected sine and cosine coefficients, the corrected phase angle (ϕ_k) was determined by

$$\phi_k = \left[\tan^{-1} (a_{ku}/b_{ku})\right] - \theta_k + k\phi_{\psi}, \tag{18}$$

where

ϕ_k = corrected phase angle
a_{ku} = uncorrected cosine coefficient
b_{ku} = uncorrected sine coefficient
θ_k = system phase lag
k = harmonic number
ϕ_{ψ} = phase angle of rotor azimuth indication (Interrupt-30 signal) - Word 37 on input tape.

System phase lag (θ_k) is the difference between parameter phase lag (θ_p) and rotor azimuth indication phase lag (θ_R), or

$$\theta_k = \theta_p - \theta_R . \tag{19}$$

This term (θ_k) was used to correct for system phase lag. The values θ_p and θ_R are obtained from phase-versus-frequency curves, based on recording path and IRIG band. The program selects the correct curves by matching the phase codes indicated in Words 38 and 39 of the input tape (these in turn come from columns 61-62 and 64-65 of the instrumentation cards). The phase angle (ϕ_{ψ}) comes from columns 56-60 of this same card. In the overall program, the phase curves were based on rotor azimuth signal (always recorded on IRIG band 13), and θ_R was set equal to zero. Plots of the phase curves appear in Figures 8, 9, and 10. In this program, lead is positive and lag is negative.

The resultant of each harmonic (R_k) was then determined by

$$R_k = \sqrt{a_{ku}^2 + b_{ku}^2} \; . \tag{20}$$

Using this and a corrected phase angle (ϕ_k), corrected cosine (a_k) and sine (b_k) coefficients were then obtained by

$$a_k = R_k \sin \phi_k \tag{21}$$

and

$$b_k = R_k \cos \phi_k \; . \tag{22}$$

In addition to these basic terms, the following supplementary data were calculated and output on each record:

Rotor Advance Ratio (μ')

$$\mu' = \frac{193.54(TAS_1)}{(RPM)(R)} \tag{23}$$

where
- μ' = rotor advance ratio
- TAS_1 = true airspeed$_1$
- RPM = rotor rpm
- R = radius to rotor blade tip.

Run Gross Weight (RGW)

$$RGW = TOGW - TOFL + TFR \tag{24}$$

where
- RGW = run gross weight
- TOGW = takeoff gross weight
- TOFL = takeoff fuel load
- TFR = total fuel remaining.

Run Center of Gravity (RCG)

$$RCG = \frac{TOGW}{RGW}(TOCG - S_{NOM} + S_{FL}) + S_{NOM} - S_{FL} \tag{25}$$

where

RCG = run center of gravity

TOCG = takeoff center of gravity

S_{NOM} = nominal cg station

S_{FL} = fuel load cg station.

Thrust-Coefficient-to-Rotor-Solidity Ratio (Forward and Aft $C_{TW/\sigma}$)

$$\begin{array}{c}\text{Fwd } C_{TW/\sigma} \\ \text{or} \\ \text{Aft } C_{TW/\sigma}\end{array} = \left[\frac{144\,(30)}{\pi}\right]^2 \left[\frac{T_F \text{ or } T_A}{b \cdot C \cdot \rho \cdot R^3 \cdot RPM^2}\right], \qquad (26)$$

where

$C_{TW/\sigma}$ = thrust-coefficient-to-rotor-solidity ratio

π = 3.1416

T_F = approximate forward rotor thrust from equation (27)

T_A = approximate aft rotor thrust from equation (28)

b = number of blades per rotor

C = blade chord in inches

ρ = air density = 0.002378 (ρ/ρ_0)

R = blade tip radius in inches

RPM = rotor rpm.

Approximate forward (T_F) and aft (T_A) thrust are given by

$$T_F = RGW\left(\frac{S_A - S_{NOM} + RCG}{S_A - S_F}\right) \qquad (27)$$

and

$$T_A = RGW\left(\frac{S_{NOM} - RCG - S_F}{S_A - S_F}\right), \qquad (28)$$

where

S_A = aft rotor station

S_F = forward rotor station.

Check Program (M42)

After harmonic analysis, the data were sufficiently reduced to permit checking. This was done automatically with a Computer Check Program (M42), which compared each parameter with a predetermined airspeed envelope and listed any terms that fell

outside the envelope. If desired, the program would first shift the indicated value (V_I) to a baseline value (V_{BL}) before checking against the envelope. This shift was used on any parameter whose value changed predictably with changes in $C_{TW/\sigma}$ and $(\mu')^2$. If ratios of these terms are combined and constant items cancelled out, the following equation results:

$$V_{BL} = V_I \left(\frac{C_{TBL} \cdot \rho_I \cdot RPM_I{}^4}{C_{TI} \cdot \rho_{BL} \cdot RPM_{BL}{}^4} \right) , \tag{29}$$

where

V_{BL} = value shifted to baseline
V_I = indicated value
C_{TBL} = baseline thrust coefficient
C_{TI} = initial thrust coefficient
ρ_I = density of air at V_I
ρ_{BL} = density of air at V_{BL}
RPM_I = rotor rpm at V_I
RPM_{BL} = rotor rpm at V_{BL}.

If V_I is on or near the forward rotor, then

$$C_{TBL} = GW_{BL} \left(\frac{D}{2} - \frac{CG_{BL}}{12}\right) \tag{30}$$

and

$$C_{TI} = GW_I \left(\frac{D}{2} - \frac{CG_I}{12}\right) . \tag{31}$$

If V_I is on or near the aft rotor, then

$$C_{TBL} = GW_{BL} \left(\frac{D}{2} + \frac{CG_{BL}}{12}\right) \tag{32}$$

and

$$C_{TI} = GW_I \left(\frac{D}{2} + \frac{CG_I}{12}\right) . \tag{33}$$

If V_I is not on or near either rotor, then

$$C_{TBL} = GW_{BL} \left(\frac{D}{2}\right) \tag{34}$$

and

$$C_{TI} = GW_I \left(\frac{D}{2}\right), \tag{35}$$

where

GW_{BL} = gross weight at V_{BL}
GW_I = gross weight at V_I
CG_{BL} = center of gravity at V_{BL} in inches
CG_I = center of gravity at V_I in inches
D = distance between rotors in feet.

Listing Program (M44)

Finally, the data tape was listed using a Listing Program (M44). This program, by use of a series of subroutines controlled by a lead (control) card, listed any digitized data tape in standard format.

After checking for error, the four or five data tapes were merged by use of IBSORT and were sorted into run order (see Figure 6). In run order, all the data from a given run and cycle are blocked together. Run order is required for analysis programs that use multiple-parameter inputs from each run.

Interaction Load Equivalents Program (C11)

After sorting into run order, the Interaction Load Equivalents Program (C11) was used to complete the force system at each gage location on the rotor blades. This was done by straight-line interpolation between existing gage locations, and, in the case of radial tension, by known blade properties.

The available rotor blade gages were all grouped at 10 spanwise locations (13-, 25-, 35-, 40-, 45-, 55-, 65-, 75-, 85-, and 95-percent span). For ease of reference, these gages will be identified as (13), (25), etc.

First, the single missing flap bending value at 13-percent span, $M_y(13)$, was determined by

$$M_y(13) = M_y(25)\left[\frac{R(25) - R(13)}{R(25) - R(F)}\right], \tag{36}$$

where

$M_y(25)$ = flap bending gage value at 25-percent span
$R(25)$ = blade station at 25-percent span
$R(13)$ = blade station at 13-percent span
$R(F)$ = blade station at flap hinge

and

$M_y(F)$ is assumed to be zero, neglecting flap bearing friction.

Then the chord bending value at 13-percent span, $M_z(13)$, was determined by

$$M_z(13) = M_z(25) \left[\frac{R(25) - R(13)}{R(25) - R(L)}\right] , \tag{37}$$

where

$M_z(25)$ = chord bending gage value at 25-percent span
$R(L)$ = percent of blade span at lag hinge

and

$M_z(L)$ is assumed to be zero, neglecting the lag damper moment.

Because of equal chordwise bending gage spacing between locations 25 and 95, the additional required chord bending values were obtained by

$$M_z(I) = \frac{M_z(I+1) + M_z(I-1)}{2} . \tag{38}$$

There were no flap shear (F_z) gages on the instrumented rotor blades. To obtain these terms, the flap bending gage values (M_y) were divided by the difference of their corresponding span locations as follows:

$$F_z(13) = - \frac{M_y(25)}{R(25) - R(F)} \tag{39}$$

and

$$F_z(I) = - \frac{M_y(I+1) + M_y(I-1)}{R(I+1) - R(I-1)}, \tag{40}$$

where

$F_z(13)$ = flapwise shear at the 13-percent radius, pounds
I = 25, 35, ... 95.

Similarly, chord shear (F_y) was obtained from chord bending (M_z) values by

$$F_y(13) = -\frac{M_z(25)}{R(25) - R(L)} \quad . \tag{41}$$

and

$$F_y(I) = -\frac{M_z(I+1) + M_z(I-1)}{R(I+1) - R(I-1)} \, . \tag{42}$$

There were only two blade torsion (M_x) gages, one at 13- and one at 40-percent span. The gage values between $M_x(13)$ and $M_x(40)$ were obtained by

$$M_x(I) = \left[\frac{M_x(40) - M_x(13)}{R(40) - R(13)}\right]\left[R(I) - R(13)\right] + M_x(13), \tag{43}$$

where
I = 25 and 35;

the gage values outboard of $M_x(40)$ were obtained by

$$M_x(I) = \left[-\frac{M_x(40)}{R - R(40)}\right]\left[R(I) - R(40)\right] + M_x(40), \tag{44}$$

where
R = rotor blade tip span.

Finally, rotor blade radial tension (F_x) was obtained from the one available tension gage at 13-percent span, $F_x(13)$. The steady tension loads at the outboard stations are determined by

$$F_x(I) = F_x(13) - \Omega^2 \Delta M(I) \Delta R(I). \tag{45}$$

The harmonic components of tension are also computed by

$$F_x(I) = F_x(13) + 2\Omega a_k(L) k \Delta M(I) \Delta R(I) \tag{46}$$

and

$$F_x(I) = F_x(13) - 2\Omega b_k(L) k \Delta M(I) \Delta R(I), \tag{47}$$

where

$\Delta R(I)$ = $\frac{1}{2}$ R(13) + R(I)
$\Delta M(I)$ = total mass between stations 13 and I
$F_x(I)$ = tension value at station I
$F_x(13)$ = tension gage value at 13-percent span
k = harmonic number
Ω = rotor speed
I = 13, 25, 35, 40, 45, 55, 65, 75, 85, and 95
$a_k(L)$ = k^{th} sine component of lag angle
$b_k(L)$ = k^{th} cosine component of lag angle.

Interaction Program (M49)

With a complete force system available at this stage for each blade gage, interaction coefficients were applied to correct the data. The program identified individual force systems by type-of-data code, station/span, and waterline/chord location. A series of 6-by-6 matrices was then employed to correct the data. Because of the method of calibration, inversion was not required, and the solution was

$$\left[F_A\right] = \begin{bmatrix}\text{Interaction}\\ \text{Coefficient}\\ \text{Matrix}\end{bmatrix} \left[F_M\right] , \tag{48}$$

where

F_A = actual loads
F_M = measured loads.

This calculation was made from the steady (A_0), sine (b_k), and cosine (a_k) coefficients only. A corrected resultant term was then calculated by

$$R_k = \sqrt{a_k^{\ 2} + b_k^{\ 2}} \tag{49}$$

and a corrected phase angle (ϕ) by

$$\phi_k = \tan^{-1}\left(\frac{a_k}{b_k}\right) . \tag{50}$$

Blade Pressure Program (M47)

After the data were processed for interaction corrections, the rotor blade pressure transducer data were input to a general pressure analysis program. The program first checked all input against a lookup table of gage locations and called out any

missing gages. The gages were then put into forward and aft span and chord arrays. The program was capable of analyzing either differential-pressure gage data or absolute gage data on the upper and lower blade surfaces, each identified by an appropriate type of data code. If given absolute gage data, the program would first determine the corresponding differential pressure by

$$\Delta P = P_L - P_U, \tag{51}$$

where

ΔP = differential pressure
P_L = absolute pressure on lower blade surface
P_U = absolute pressure on upper blade surface.

With all data then in terms of differential pressure, calculations were started. First, lift per unit span (ΔL) was calculated for each span survey location by obtaining the incremental lift between each gage from

$$\Delta L = \Delta L_1 + \Delta L_2 + \ldots \Delta L_N \quad , \tag{52}$$

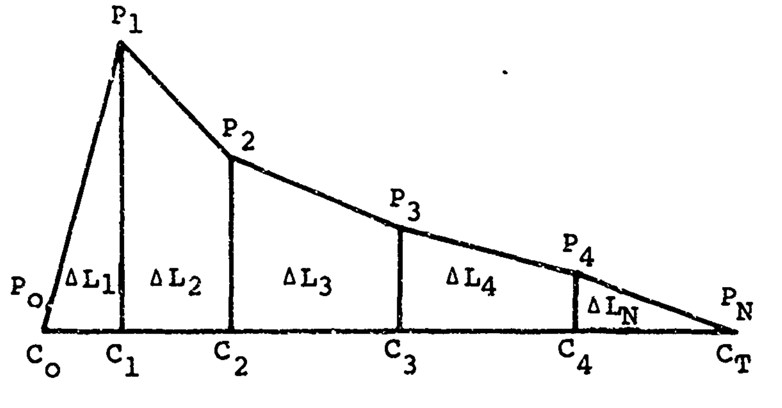
where

$$\Delta L_1 = \frac{P_o + P_1}{2} (C_1 - C_o)$$

$$\Delta L_2 = \frac{P_1 + P_2}{2} (C_2 - C_1)$$

etc., and

P_1, P_2, etc. = differential blade pressures
C_1, C_2, etc. = corresponding chordwise locations.



In these calculations, C_o, P_o, and P_N were always set equal to zero, and C_T was set equal to the blade chord.

Next, pitch moment arm ($\Delta\bar{C}_N$) was calculated for each incremental lift by

$$\Delta\bar{C}_1 = -\left[\frac{(C_1 - C_o)\ (2\ P_1 + P_o)}{3\ (P_1 + P_o)}\right] - C_o + C_R, \tag{53}$$

$$\Delta\bar{C}_2 = -\left[\frac{(C_2 - C_1)\ (2\ P_2 + P_1)}{3\ (P_2 + P_1)}\right] - C_1 + C_R,$$

etc.,

where

C_R = pitch moment reference position, inches from leading edge of blade.

The pitch moment per unit span (ΔM) was then given by

$$\Delta M = (\Delta L_1 \cdot \Delta\bar{C}_1) + (\Delta L_2 \cdot \Delta\bar{C}_2) + \ldots\ (\Delta L_N \cdot \Delta\bar{C}_N), \tag{54}$$

and the pitch moment arm ($\Delta\bar{C}$) was given by

$$\Delta\bar{C} = \frac{\Delta M}{\Delta L}\ . \tag{55}$$

With these terms calculated for each span survey location, the total lift per blade (L) was then calculated by

$$L = L_1 + L_2 + \ldots\ L_N, \tag{56}$$

where

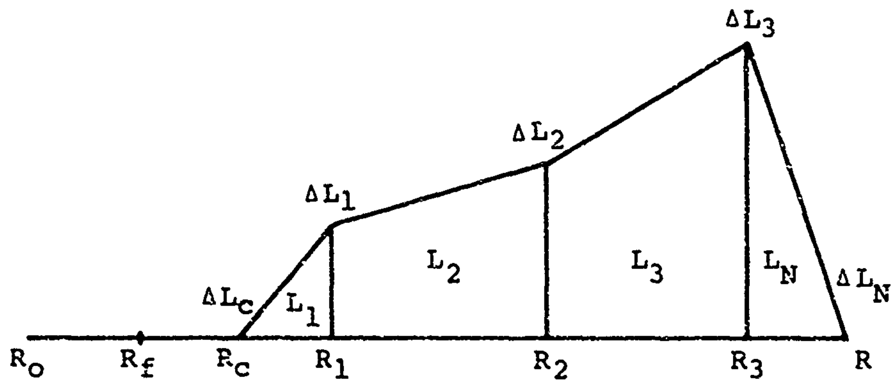
$$L_1 = \frac{\Delta L_c + \Delta L_1}{2}\ (R_1 - R_c),$$

$$L_2 = \frac{\Delta L_1 + \Delta L_2}{2}\ (R_2 - R_1),$$

and

R_c = blade span at start of airfoil.

Here, again, ΔL_c and ΔL_N were always set equal to zero and R was set equal to blade span.



The root aerodynamic moment arm ($\Delta\bar{R}_N$) for each section was then calculated by

$$\Delta\bar{R}_1 = \frac{(R_1 - R_c)\ (2\Delta L_1 + \Delta L_c)}{3\ (\Delta L_1 + \Delta L_c)} + R_c - R_f, \tag{57}$$

$$\Delta\bar{R}_2 = \frac{(R_2 - R_1)\ (2\Delta L_2 + \Delta L_1)}{3\ (\Delta L_2 + \Delta L_1)} + R_1 - R_f,$$

where
R_c = blade span at start of airfoil
R_f = blade span at flap hinge.

The root aerodynamic flap moment (M_f) was then calculated by

$$M_f = (L_1 \cdot \Delta\bar{R}_1) + (L_2 \cdot \Delta\bar{R}_2) \ldots (L_N \cdot \Delta\bar{R}_N) \tag{58}$$

and the blade flap moment arm ($\bar{R}$) by

$$\bar{R} = \frac{M_f}{L} . \tag{59}$$

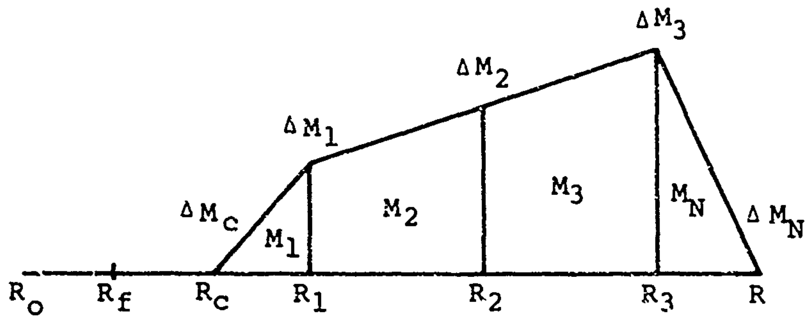
Finally, the pitch moment per blade (M_p) was calculated by

$$M_p = M_1 + M_2 + \ldots M_N , \tag{60}$$

where

$$M_1 = \frac{\Delta M_c + \Delta M_1}{2} (R_1 - R_c)$$

$$M_2 = \frac{\Delta M_1 + \Delta M_2}{2} (R_2 - R_1), \text{ etc.}$$



Here, again, ΔM_c and ΔM_N were always set equal to zero and R was set equal to blade span.

STANDARD OUTPUT DATA RECORD

Every data record generated by the digitized flight data program was in standard format. This consisted of a 44-word header of flight, run, and parameter information followed by N data words. While the term in a given word might vary from program to program, the type of format (BCD, fixed-point, etc.) never varied. In general, the header varied only slightly between programs. The standard data record described here is that appearing on the report data tape. Most of the header was generated by the Primary Load Calibration Program (M40), and the data words were in the format generated by the Harmonic Analysis Program (M43). The format of this standard record is shown in Table I.

TABLE I
IDENTIFICATION OF DATA IN STANDARD OUTPUT DATA RECORD

Item	Units	Tape Word	Format Type	Source Program
Record identification	-	1	fixed-point	M43 - identifies harmonic analysis format
Aircraft	-	2-3	BCD (8 characters)	M40 - from flight card data

TABLE I - Continued

Item	Units	Tape Word	Format Type	Source Program
Flight	-	4	fixed-point	M40 - from flight card data
Date	MODAYR	5	fixed-point	M40 - from flight card data
Gross weight	lb	6	floating-point	M40 - from flight card data
Center of gravity	in.	7	floating-point	M40 - from flight card data
Run number	-	8	floating-point	M40 - from flight card data
Cycle number in run	-	9	floating-point	M40 - generated by program
Maneuver (code)	-	10	fixed-point	M40 - from flight card data
Rotor rpm	-	11	floating-point	M40 - from flight card data
Indicated airspeed	knots	12	floating-point	M40 - from flight card data
Pressure altitude	ft	13	floating-point	M40 - from flight card data
Ambient air temperature	deg C	14	floating-point	M40 - from flight card data
True airspeed$_1$	knots	15	floating-point	M40 - calculated from flight card data
Density altitude$_1$	ft	16	floating-point	M40 - calculated from flight card data
True airspeed$_2$	knots	17	floating-point	M40 - calculated from digital data
Density altitude$_2$	ft	18	floating-point	M40 - calculated from digital data
Forward cyclic trim position	deg	19	floating-point	M40 - from flight card data
Aft cyclic trim position	deg	20	floating-point	M40 - from flight card data
Forward $C_{TW/\sigma}$	-	21	floating-point	M43 - calculated from flight card data
Aft $C_{TW/\sigma}$	-	22	floating-point	M43 - calculated from flight card data

TABLE I - Continued

Item	Units	Tape Word	Format Type	Source Program
Test point number	-	23	floating-point	M40 - from flight card data
Ambient air temperature in hangar	deg C	24	floating-point	M40 - from flight card data
Control words 1-9	-	25-27	BCD (9 characters)	M40 - from flight card data
Identification code	-	28	fixed-point	M40 - from flight card data
Type-of-data code	-	29	fixed-point	M40 - from flight card data
Station (or span)	in.	30	floating-point	M40 - from flight card data
Waterline (or chord)	in.	31	floating-point	M40 - from flight card data
Buttline	in.	32	floating-point	M40 - from flight card data
Units	-	33,34	BCD (7 characters)	M40 - from flight card data
Parameter identification	-	35-38	BCD (13 characters	M40 - from flight card data
Run center of gravity	in.	39	floating-point	M43 - calculated from flight card data
Run gross weight	lb	40	fixed-point	M43 - calculated from flight card data
Blank	-	41	fixed-point	
Advance ratio (μ')	-	42	floating-point	M43 - calculated from flight card data
Interval time between samples	millisec	43	floating-point	M40
Number of data words	-	44	fixed-point	M43
		*** End of Header ***		
Steady term (A_0)	-	45	floating-point	M43
Resultant term of first harmonic (R_1)	-	46	floating-point	M43
Cosine coefficient of first harmonic (a_1)	-	47	floating-point	M43

TABLE I - Continued

Item	Units	Tape Word	Format Type	Source Program
Sine coefficient of first harmonic (b_1)	-	48	floating-point	M43
Phase angle of first harmonic (ϕ_1)	-	49	floating-point	M43
Resultant term of second harmonic...etc.	-	50	floating-point	M43
Phase angle of twelfth harmonic (ϕ_{12})	-	93	floating-point	M43

In the standard header there are four terms (Aircraft, Control Words, Units, and Parameter) which are in alphanumeric format and are represented by more than one header word. These words are always written on tape in the format shown in Table II.

TABLE II
STANDARD HEADER IDENTIFICATION OF
ALPHANUMERIC WORDS

Word	Term			
	Aircraft (8 alpha-numeric)	Control Words (9 alpha-numeric)	Units (7 alpha-numeric)	Parameter (13 alpha-numeric)
2	1st 6 letters			
3	last 2 letters			
25		1st 6 letters		
26		last 3 letters		
32			1st 6 letters	
33			last letter	
34				1st 6 letters
35				2nd 6 letters
36				last letter

FILE DESCRIPTION OF PROCESSED DATA TAPE

The data tapes generated by all digital analysis programs conformed to an identical format. Each logical record contained a 44-word header of flight, run, and parameter information followed by a variable number of data values. The 44th header word listed the number of data values.

Data on the tapes were sorted in the following order before analysis in the second phase of the data path and remained in this order throughout the completion of analysis, editing, and final correction:

1. Major sort on run number.
2. First minor sort on cycle number.
3. Second minor sort on parameter (data code).

Tape Specifications

The output tape generated on the IBM S/360-65 conforms to the following specifications (see Figure 18):

A. Physical characteristics

   1. Standard 80-character BCD header and trailer labels.
   2. Data set name (DSNAME), M40A/D.
   3. Block size, 6244 bytes.
   4. Logical record length, 624 bytes.
   5. Tape density, 800 BPI.
   6. Tape, 9-track.
   7. Record format (RECFM), variable blocked.

B. Internal characteristics

   1. Binary tape.
   2. Variable length records blocked 10 up.
   3. Minimum record length, 47 words (188 bytes).
   4. Maximum record length, 156 words (624 bytes).

C. System control words

   1. System generates a block control word (4 bytes) at the start of each block (physical record).
   2. System generates two 4-byte control words at the start of each logical record.

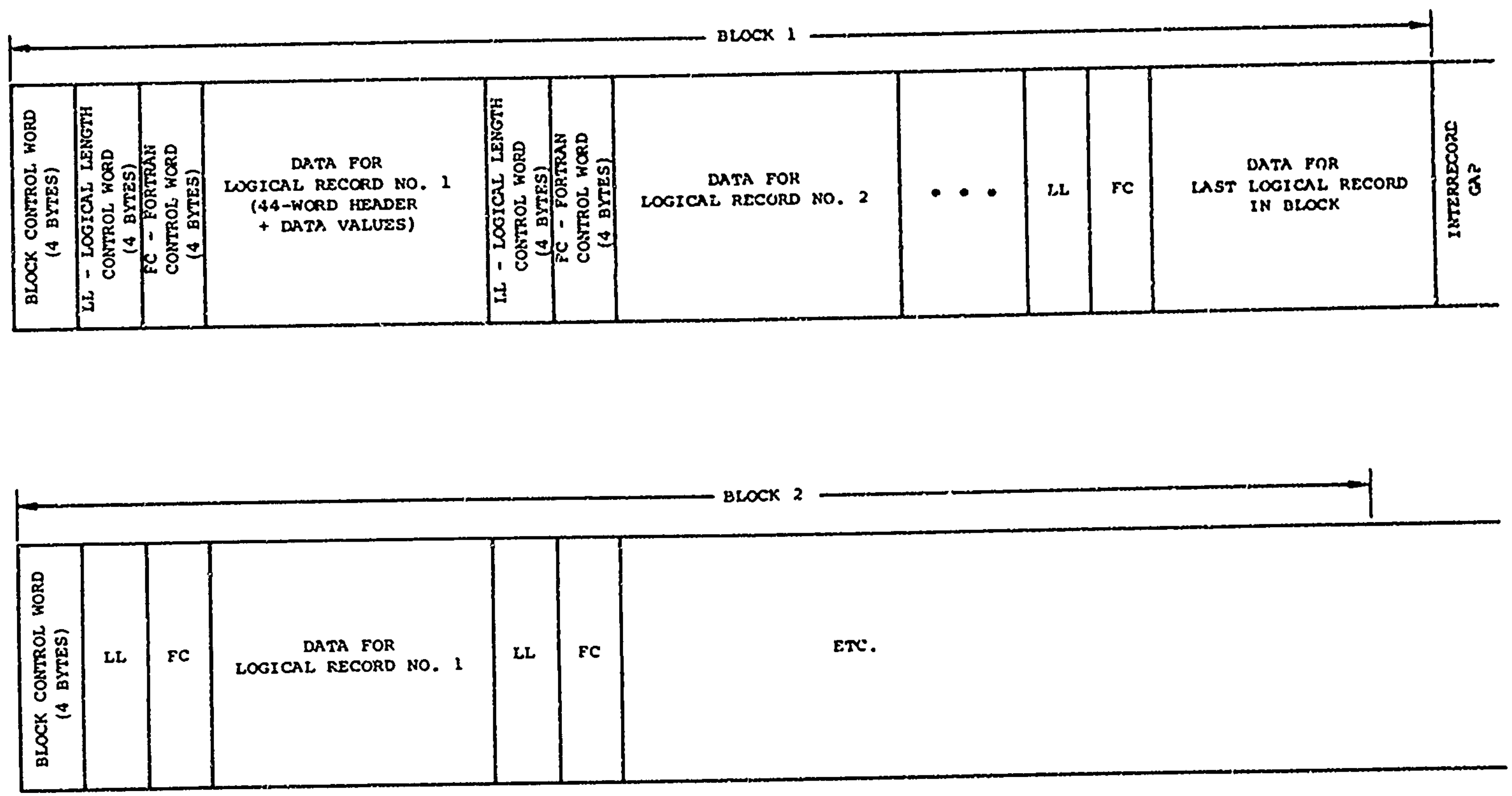


Figure 18. Data Tape Schematic Diagram.

SUBSTANTIATION OF PROPER OPERATION OF DATA SYSTEM

Because of the complexity of the data paths and the anticipated volume of data, considerable attention was given to program and data checkout. Each program was analyzed to determine possible sources of error, and then given a series of test cases to check out all manipulations and calculations. During checkout, the programs were given a number of extra output statements so that calculations could be checked step by step through the program. A major program such as the Calibration Program (M40) required more than 40 such individual tests.

To improve computational reliability, each program incorporated a series of system error checks (library subroutine errors) and messages which identified illogical computations and values (such as an attempt to divide by zero). In addition, an analysis was made of each program at the time of inception, and a series of error checks and appropriate messages was provided to indicate if various anticipated operational errors occurred. In the Calibration Program (M40), more than 20 such checks were incorporated.

After performing a checkout with test cases, each program was checked with a tape of actual flight data. This was a test for unanticipated variations in data, since experience had shown that no test case ever completely duplicated real test data.

SYSTEM FUNCTIONAL TESTS

As a complete check on the instrumentation and data processing systems, functional tests were made on the test aircraft. In these tests, known values were recorded on the aircraft instrumentation system. These records were then digitized and processed in the normal manner and compared with the known input values for error. The functional check thus served as a test of the entire data acquisition and reduction system.

Table XV in Appendix IV is a synopsis of the first three records of Functional Test F394, the test which most closely approximated actual flight conditions.

These records were as follows:

1. Baseline data on rotor head gages after preflight calibration and 3 hours of warmup.
2. Same baseline data, after in-flight calibration to

compensate for drift during a 3-hour warmup.

3. Signal simulation on rotor head gages equal to the calibration equivalent.

For comparison, these values were expressed as percent deviation from full scale and analyzed to determine the following:

1. Arithmetic mean $\bar{X} = \frac{\sum X}{N}$.
2. Average deviation from mean MD = $\frac{\sum (X - \bar{X})}{N}$.
3. Standard deviation $\sigma = \sqrt{\frac{\sum (X - \bar{X})^2}{N}}$.
4. 2σ confidence level.

The values obtained, in percent deviation of full scale, were as shown in Table III.

TABLE III
STATISTICAL ANALYSIS OF FUNCTIONAL CHECK F394

Record	Arithmetic Mean ($\bar{X}$)	Average Deviation (MD)	Standard Deviation σ	2σ Confidence Level
1. Baseline data before in-flt cal	1.02	±0.95	1.48	2.96
2. Baseline data after in-flt cal	0.55	0.40	0.58	1.16
3. Signal equal to cal equivalent	1.11	±0.68	1.09	2.18

These results illustrate the general high level of accuracy obtained in this program, both by the instrumentation and by the data analysis system. Note especially the marked improvement in accuracy after an in-flight calibration. These calibrations, recorded and digitized automatically after each data record, compensated for VCO and amplifier drift.

TYPICAL CHECK CASES FOR DATA PROCESSING PROGRAMS

To ensure correct operation, test cases were run on each computer program in the data path. This was done with actual flight data in the case of the simpler routines and with sample

cases on the more mathematically complex solutions. This section gives samples of the basic reduction routines used to process data for the Dynamic Airloads Program.

Primary Loads Calibration Program (M40)

This test case was taken from the flight data. The sample illustrated is the first ordinate (sample) from Data Code 4186 on Run 4 of Flight 384.

First, the raw digitized value (V_R) in counts was corrected for VCO and amplifier drift by the equation

$$V_C = (V_R - BL_{INF}) \left[\frac{BW_{PRE} - VCO_{PRE}}{BW_{INF} - VCO_{INF}} \right] , \tag{61}$$

where

V_C = corrected digitized value in counts
V_R = 1621 = raw digitized value in counts
BL_{INF} = 1956 = in-flight baseline in counts
BW_{PRE} = 298 = preflight 40-percent bandwidth in counts
BW_{INF} = 332 = in-flight 40-percent bandwidth in counts
VCO_{PRE} = 1728 = preflight VCO center frequency in counts
VCO_{INF} = 1749 = in-flight VCO center frequency in counts.

Then,

$$V_C = (1621 - 1956) \left[\frac{298 - 1728}{332 - 1749} \right] = -338.07 \text{ counts.}$$

A real engineering value (V_C) was then calculated from the corrected engineering value by

$$V_E = \left[\frac{V_C - (BIAS - BL_{PRE})}{Rcal - EZ} \right] EQUIV + X_O , \tag{62}$$

where

V_E = real engineering value
V_C = -338.07 = corrected engineering value in counts
BIAS = 1444 = bias in counts
BL_{PRE} = 1411 = preflight baseline in counts
Rcal = 221 = Rcal in counts
EZ = 1461 = electrical zero in counts
EQUIV = 0.5 = calibration equivalent in psi
X_O = 0 = zero reference level in engineering units;

then,

$$V_E = \left[\frac{-338.07 - (1444 - 1411)}{221 - 1461}\right] 0.5 + 0 = 0.1496 \text{ psi.}$$

The M40 program gave an answer of 0.1497 for this point. The small difference between these values is due to roundoff in the calibration values, each of which is an average of five samples rather than the simple integer printed on each of the listings used in this case.

Averaging Program (M31)

This program, which averaged consecutive rotor cycles in each run, was tested with actual data from Flight 384 by inserting a Listing Program before and after the Averaging Program. Flight 384 data were chosen, since the number of ordinates in this flight was not identical on all cycles of a run. The results are shown in Table IV.

TABLE IV
TEST CASE FOR AVERAGING PROGRAM

Data Code 4248 Run 3			
Cycle	1st Ordinate	26th Ordinate	69th Ordinate
1	3.67	3.46	3.73
2	3.64	3.46	3.64
3	3.62	3.46	-
4	3.60	3.50	-
5	3.53	3.42	-
Average	3.612	3.460	3.685
M31 Average	3.61	3.46	3.69

This table shows that the program not only was averaging 5 cycles correctly but also was averaging correctly when less than 5 cycles were present, as illustrated by the 69th ordinate.

Harmonic Analysis Program (M43)

To test this program, waveforms of known harmonic content were

generated by use of 5-place trigonometric tables. This was done to avoid the tedious and error-prone hand calculation involved in the analysis of a waveform of unknown harmonic content. The 60-ordinate test case listed in Table V contains harmonics 1 through 6, each with a value of one and a phase of zero.

The results of this test case are listed in Table VI. Note that the 6 input harmonics are correctly identified and analyzed and that there is no loss in significant digits.

TABLE V
ORDINATE VALUES FOR HARMONIC ANALYSIS TEST

Ordinate	Value	Ordinate	Value
0	0.00000	30	0.00000
1	2.11599	31	0.28889
2	3.76267	32	0.43921
3	4.60795	33	0.37187
4	4.54928	34	0.10162
5	3.73206	35	-0.26794
6	2.48991	36	-0.58779
7	1.22952	37	-0.72678
8	0.30052	38	-0.62935
9	-0.10648	39	-0.34256
10	0.00000	40	0.00000
11	0.44094	41	0.23188
12	0.95106	42	0.22452
13	1.28379	43	-0.05447
14	1.29845	44	-0.52053
15	1.00000	45	-1.00000
16	0.52053	46	-1.29845
17	0.05447	47	-1.28379
18	-0.22452	48	-0.95106
19	-0.23188	49	-0.44094
20	0.00000	50	0.00000
21	0.34256	51	0.10648
22	0.62935	52	-0.30045
23	0.72678	53	-1.22952
24	0.58779	54	-2.48991
25	0.26794	55	-3.73206
26	-0.10162	56	-4.54928
27	-0.37187	57	-4.60795
28	-0.43921	58	-3.76267
29	-0.28889	59	-2.11599

TABLE VI
RESULTS OF HARMONIC ANALYSIS TEST

Harmonic	Resultant	Cosine Coefficient	Sine Coefficient	Phase Angle
1	1.000005	-0.000004	1.000005	359.9998
2	1.000004	-0.000001	1.000004	359.9999
3	1.000006	-0.000001	1.000006	359.9999
4	1.000004	-0.000002	1.000004	359.9998
5	1.000008	0.000000	1.000008	360.0000
6	1.000010	0.000004	1.000010	0.0002
7	0.000004	0.000004	0.000002	57.8899
8	0.000003	0.000002	-0.000002	138.8016
9	0.000001	0.000001	0.000001	63.3989
10	0.000003	0.000003	0.000000	86.6191
11	0.000004	0.000002	-0.000003	135.6226
12	0.000002	0.000000	-0.000002	182.8980

Interaction Program (M49)

To test this program, an M43-type data tape was created containing known harmonic components. This was processed through M49 with known interaction coefficients, and the answers were then checked against hand calculations.

The input harmonic components are listed in Table VII and the interaction coefficients in Table VIII. For ease in calculation, all values were rounded off. The output, listed in Table IX, contained exactly the anticipated values, again with no loss in significant digits.

TABLE VII
M43 DATA INPUT

Force	Type of Data	Steady Term	1st Harm. Cosine Coeff	1st Harm. Sine Coeff	2nd Harm. Cosine Coeff	2nd Harm. Sine Coeff
F_x	20	1000.	-2000.	3000.	4000.	-5000.
F_y	21	2000.	-3000.	1000.	5000.	-2000.
F_z	22	3000.	-4000.	2000.	2000.	-3000.
M_x	23	1000.	1000.	-3000.	1000.	-4000.
M_y	24	2000.	2000.	-2000.	3000.	-1000.
M_z	25	3000.	3000.	-1000.	2000.	-4000.

TABLE VIII
M49 INTERACTION COEFFICIENTS

Force	Type of Data	1st Coeff	2nd Coeff	3rd Coeff	4th Coeff	5th Coeff	6th Coeff
F_x	20	1.0	0.4	0.6	0.8	0.2	0.1
F_y	21	0.2	1.0	0.8	0.6	0.8	0.4
F_z	22	0.8	0.6	1.0	0.4	0.6	0.6
M_x	23	0.6	0.8	0.2	1.0	0.4	0.8
M_y	24	0.4	0.2	0.4	0.2	1.0	0.2
M_z	25	1.0	0.2	0.8	0.6	0.4	1.0

TABLE IX
M49 DATA OUTPUT

Force	Type of Data	Steady Term	1st Harm. Cosine Coeff	1st Harm. Sine Coeff	2nd Harm. Cosine Coeff	2nd Harm. Sine Coeff
F_x	20	5100.	-4100.	1700.	8800.	-11400.
F_y	21	8000.	-3200.	-600.	11200.	-10200.
F_z	22	8400.	-4000.	2000.	11600.	-12800.
M_x	23	7000.	-200.	-1600.	10600.	-12800.
M_y	24	4800.	-200.	-600.	7000.	-6200.
M_z	25	8200.	-1400.	1200.	10400.	-14600.

Blade Pressure Program (M47)

This program was checked in two different ways. First, an idealized test case was input. A second, more interesting, check was then made with tabular data obtained from TM X952.* These rotor blade airload data were presented both as differential pressures around the azimuth and as calculated lift per unit span for each harmonic. This form of presentation permitted a cross-check of the M47 Program. The differential pressures were card-input, harmonically analyzed with the M43 program, and put into M47, which calculated lift per unit span.

*J. Scheiman, A Tabulation of Helicopter Rotor Blade Differential Pressures, Stresses, and Motions as Measured in Flight, NASA TM X952, March 1964.

This term could then be checked against the lift per unit span from TM X952. The only major difference between the two analytical methods was that the reference data were integrated to determine lift per unit span before harmonic analysis, rather than after harmonic analysis as in M47. This may have affected some of the smaller values obtained for the higher harmonics.

Table X and Figures 19 and 20 are comparisons of data from TM X952 and from the Blade Pressure Program. The test data used were for Flight Number 14 which was a steady level-flight data point at 104 knots. In general, the data compare closely in spite of the different methods of integration. The largest absolute errors lie in the steady term and first two harmonics at 85-percent radius. It is felt that this is due to the large number of chordwise pressure pickups on the rotor at this blade station (11 as compared to 5 to 7 at other stations), and in particular to the existence of a pickup at 4-percent chord, an area of relatively high pressure. The Blade Pressure Program was compared with other data from TM X952, and similar results were obtained, with the largest error again at the 85-percent radius. The data at 85-percent radius were then hand-checked to ascertain if there were any computer program-induced errors at this radius. There were none.

TABLE X
COMPARISON OF M47 AND TM X952 BLADE PRESSURE DATA

Harmonic	Percent Radius							
	25		40		55		75	
	M47	X952	M47	X952	M47	X952	M47	X952
0	2.28	2.41	5.31	5.64	9.96	10.02	16.20	16.22
1	-2.84	-2.68	-3.52	-3.31	-3.43	-3.13	-0.30	-0.19
2	1.41	1.22	1.72	1.58	3.51	3.68	3.91	4.32
3	-0.58	-0.38	-0.61	-0.37	0.23	0.35	0.46	0.90
4	0.02	-0.09	-0.24	-0.32	-0.34	-0.17	0.09	-0.15
5	-0.23	-0.24	0.02	-0.06	-0.02	-0.20	0.31	0.15
6	0.14	0.04	0.02	0.02	0.15	0.27	0.06	0.11
7	-0.03	-0.04	-0.01	0.02	0.00	-0.09	-0.05	0.06
8	-0.00	-0.04	-0.01	0.02	-0.05	0.02	0.16	0.18
9	0.01	0.03	-0.10	-0.07	0.01	-0.05	-0.04	0.06
10	-0.01	-0.05	-0.01	-0.06	-0.04	0.01	-0.03	-0.10

TABLE X - Continued

Harmonic	Percent Radius					
	85		90		95	
	M47	X952	M47	X952	M47	X952
0	19.99	22.22	21.08	21.06	20.22	20.37
1	2.12	2.83	4.79	4.30	5.31	4.88
2	4.63	5.48	4.31	4.65	3.09	3.31
3	1.63	1.53	1.10	1.20	0.53	0.45
4	0.71	0.58	0.95	0.86	1.03	1.01
5	-0.43	-0.37	-0.29	-0.48	-0.15	-0.22
6	0.30	0.22	0.17	0.09	-0.11	-0.26
7	0.03	-0.01	-0.22	-0.02	-0.23	-0.17
8	-0.07	-0.05	-0.23	-0.13	-0.09	0.11
9	0.03	-0.02	0.02	0.08	-0.02	0.14
10	0.09	-0.07	0.23	0.11	0.13	-0.05

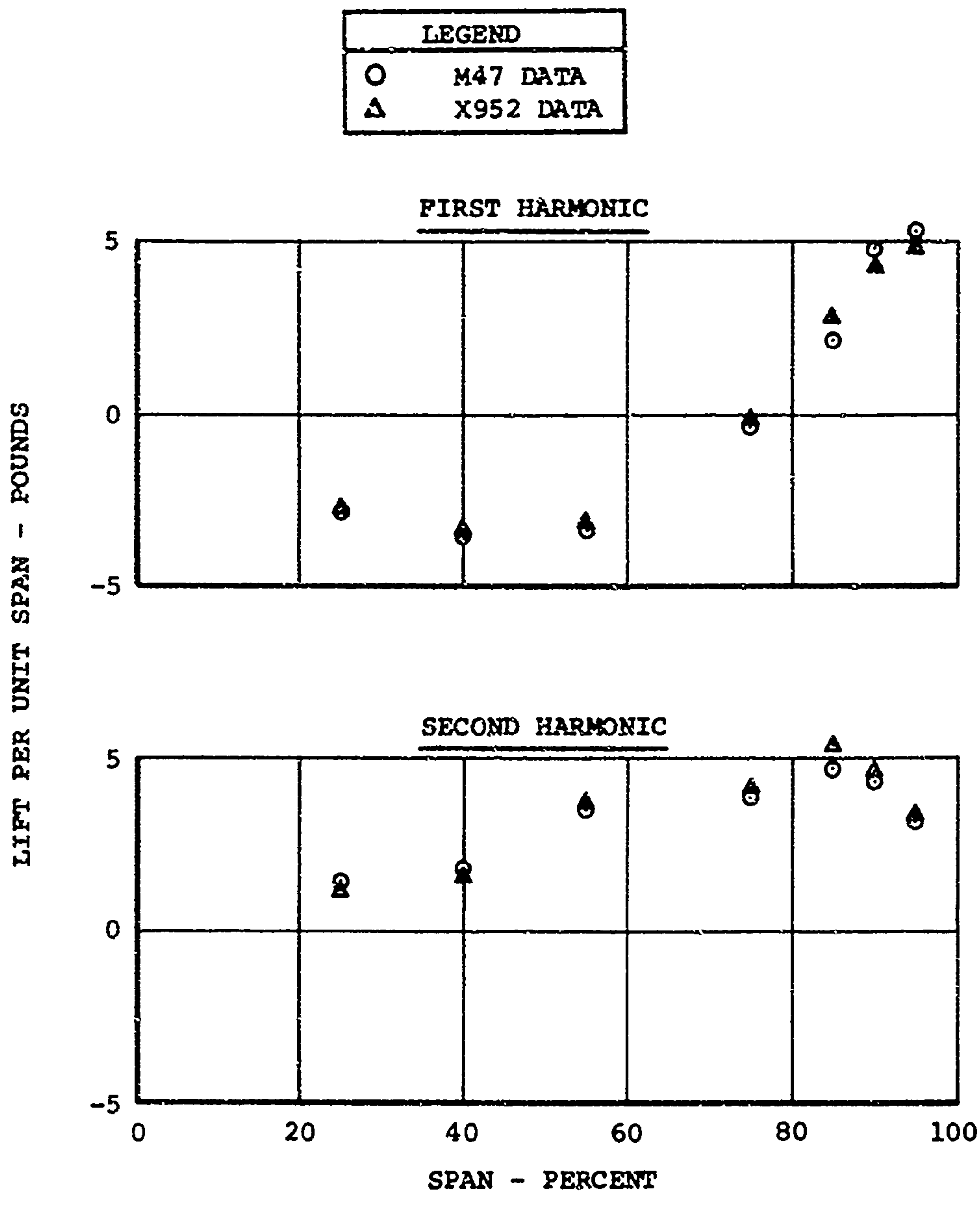


Figure 19. Comparison of First and Second Harmonic Cosine Coefficients from TM X952 and from the Blade Pressure Program (M47).

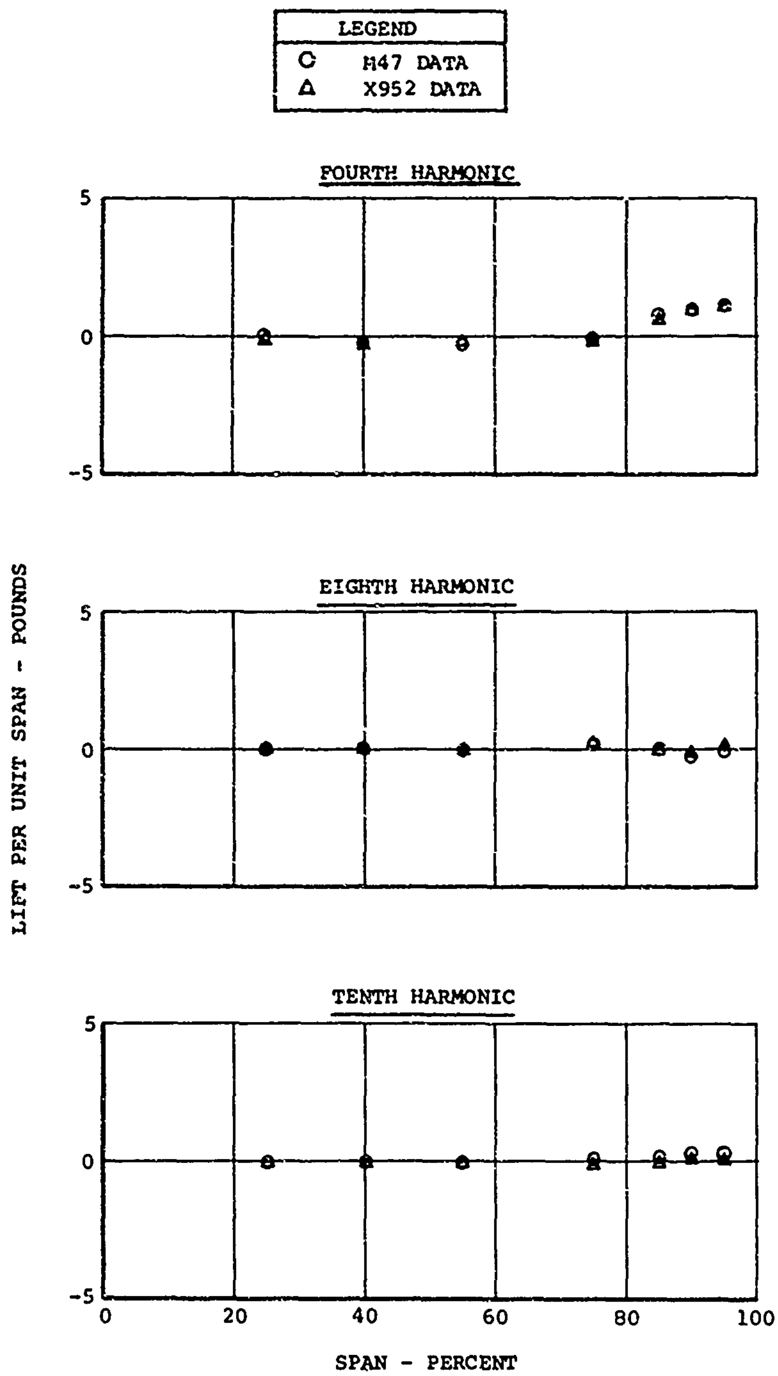


Figure 20. Comparison of Fourth, Eighth, and Tenth Harmonic Cosine Coefficients from TM X952 and from the Blade Pressure Program (M47)

APPENDIX I

LIST OF DATA IDENTIFICATION CODES

The following computer listing identifies all codes, words, and abbreviations that were assigned to data throughout the course of the Dynamic Airloads Program.

DATA CODE AND PARAMETER IDENTIFICATION

DATA CODE	INSTR. CODE	DATA TYPE CODE	DESCRIPTION
1044	A44	90	FROT ACC YBLD
1044	A44		ROTATING ACCELEROMETER FWD YELLOW BLADE
1045	A45	91	FROT ACC GBLD
1045	A45		ROTATING ACCELEROMETER FWD GREEN BLADE
1046	A46	92	FROT ACC RBLD
1046	A46		ROTATING ACCELEROMETER FWD RED BLADE
1047	A47	93	AROT ACC YBLD
1047	A47		ROTATING ACCELEROMETER AFT YELLOW BLD
1048	A48	94	AROT ACC GBLD
1048	A48		ROTATING ACCELEROMETER AFT GREEN BLADE
1049	A49	95	AROT ACC RBLD
1049	A49		ROTATING ACCELEROMETER AFT RED BLADE
2018	D18	00	F SW ACT POSN
2018	D18		FORWARD SWIVELING ACTUATOR POSITION
2019	D19	00	F PIV AC POSN
2019	D19		FORWARD PIVOTING ACTUATOR POSITION
2020	D20	00	FCYC TRM POSN
2020	D20		FWD LONG. CYC. TRIM ACT. POS-ROTOR HEAD
2021	D21	00	A PIV AC POSN
2021	D21		AFT PIVOTING ACTUATOR POSITION
2022	D22	00	A SW ACT POSN
2022	D22		AFT SWIVELING ACTUATOR POSITION
2023	D23	00	ACYC TRM POSN
2023	D23		AFT LONG. CYC. TRIM ACT. POS-ROTOR HEAD
2024	D24	00	FWD BLD PITCH
2024	D24		FORWARD BLADE PITCH ANGLE
2025	D25	00	AFT BLD PITCH
2025	D25		AFT BLADE PITCH ANGLE
2026	D26	06	FWD BLD FLAP
2026	D26		FORWARD BLADE FLAP ANGLE
2027	D27	07	AFT BLD FLAP
2027	D27		AFT BLADE FLAP ANGLE
2028	D28	16	FWD BLD LAG
2028	D28		FORWARD BLADE LEAD-LAG ANGLE
2029	D29	17	AFT BLD LAG
2029	D29		AFT BLADE LEAD-LAG ANGLE

DATA CODE	INSTR. CODE	DATA TYPE CODE	DESCRIPTION
2034	D34	00	ANGLE ATTACK
2034	D34		ANGLE OF ATTACK-BOOM VANE
2035	D35B	00	SIDE SLIP-B
2035	D35B		ANGLE OF SIDESLIP-BOOM VANE
7035	D35H	00	SIDE SLIP-H
7035	D35H		ANGLE OF SIDESLIP-ROTOR HUB VANE
3017	M17	00	YAW HEADING
3017	M17		GYRO COMPASS HEADING
3027	M27	00	1 REV SIGNAL
3027	M27		1/REV SIGNAL-FORWARD ROTOR HEAD
3052	M52	00	PITCH ATTITUD
3052	M52		PITCH ATTITUDE-GYRO
3053	M53	00	ROLL ATTITUDE
3053	M53		ROLL ATTITUDE-GYRO
3054	M54	00	RECORD CODER
3054	M54		RECORD CODER
3069	M69	00	INTERCOM
3069	M69		INTERCOM
4105	P105B	03	IND A/S SEQ1
4105	P105B		DYNAMIC AIR PRESSURE-BOOM SYSTEM
9105	P105B	03	IND A/S SEQ2
9105	P105B		DYNAMIC AIR PRESSURE-BOOM SYSTEM
4106	P106B	04	PRES ALT SEQ1
4106	P106B		STATIC PRESSURE-BOOM SYSTEM
9106	P106B	04	PRES ALT SEQ2
9106	P106B		STATIC PRESSURE-BOOM SYSTEM
4177	P177	10	FBLD ABS PR
4177	P177		ABSOLUTE PRESSURE PAIR-FWD BLD (25-2)
4178	P178	10	FBLD ABS PR
4178	P178		ABSOLUTE PRESSURE PAIR-FWD BLD (25-9)
4179	P179	10	FBLD ABS PR
4179	P179		ABSOLUTE PRESSURE PAIR-FWD BLD (25-23)
4180	P180	10	FBLD DIFF PR
4180	P180		DIFFERENTIAL PRESSURE-FWD BLADE (25-47)
4181	P181	10	FBLD DIFF PR
4181	P181		DIFFERENTIAL PRESSURE-FWD BLADE (25-77)

DATA CODE	INSTR. CODE	DATA TYPE CODE	DESCRIPTION
4182	P182	10	FBLD ABS PR
4182	P182		ABSOLUTE PRESSURE PAIR-FWD BLD (40-2)
4183	P183	10	FBLD ABS PR
4183	P183		ABSOLUTE PRESSURE PAIR-FWD BLADE (40-9)
4184	P184	10	FBLD ABS PR
4184	P184		ABSOLUTE PRESSURE PAIR-FWD BLD (40-23)
4185	P185	10	FBLD DIFF PR
4185	P185		DIFFERENTIAL PRESSURE-FWD BLD (40-47)
4186	P186	10	FBLD DIFF PR
4186	P186		DIFFERENTIAL PRESSURE FWD BLADE (40-77)
4187	P187	10	FBLD ABS PR
4187	P187		ABSOLUTE PRESSURE PAIR-FWD BLADE (55-2)
4188	P188	10	FBLD ABS PR
4188	P188		ABSOLUTE PRESSURE PAIR-FWD BLADE (55-9)
4189	P189	10	FBLD ABS PR
4189	P189		ABSOLUTE PRESSURE PAIR-FWD BLD (55-23)
4190	P190	10	FBLD DIFF PR
4190	P190		DIFFERENTIAL PRESSURE-FWD BLD (55-34
4191	P191	10	FBLD DIFF PR
4191	P191		DIFFERENTIAL PRESSURE-FWD BLD (55-47)
4192	P192	10	FBLD DIFF PR
4192	P192		DIFFERENTIAL PRESSURE-FWD BLD (55-63)
4193	P193	10	FBLD DIFF PR
4193	P193		DIFFERENTIAL PRESSURE-FWD BLD (55-92)
4194	P194	10	FBLD ABS PR
4194	P194		ABSOLUTE PRESSURE PAIR-FWD BLADE (75-2)
4195	P195	10	FBLD ABS PR
4195	P195		ABSOLUTE PRESSURE PAIR-FWD BLADE (75-9)
4196	P196	10	FBLD ABS PR
4196	P196		ABSOLUTE PRESSURE PAIR-FWD BLD (75-23)
4197	P197	10	FBLD DIFF PR
4197	P197		DIFFERENTIAL PRESSURE-FWD BLD (75-35)
4198	P198	10	FBLD DIFF PR
4198	P198		DIFFERENTIAL PRESSURE-FWD BLD (75-47)
4199	P199	10	FBLD DIFF PR
4199	P199		DIFFERENTIAL PRESSURE-FWD BLD (75-63)

DATA CODE	INSTR. CODE	DATA TYPE CODE	DESCRIPTION
4200	P200	10	FBLD DIFF PR
4200	P200		DIFFERENTIAL PRESSURE-FWD BLD (75-88)
4201	P201	10	FBLD ABS PR
4201	P201		ABSOLUTE PRESSURE PAIR-FWD BLADE (85-2)
4202	P202	10	FBLD ABS PR
4202	P202		ABSOLUTE PRESSURE PAIR-FWD BLADE (85-4)
4203	P203	10	FBLD ABS PR
4203	P203		ABSOLUTE PRESSURE PAIR-FWD BLADE (85-9)
4204	P204	10	FBLD ABS PR
4204	P204		ABSOLUTE PRESSURE PAIR-FWD BLD (85-13)
4205	P205	10	FBLD ABS PR
4205	P205		ABSOLUTE PRESSURE PAIR-FWD BLD (85-17)
4206	P206	10	FBLD ABS PR
4206	P206		ABSOLUTE PRESSURE PAIR-FWD BLD (85-23)
4207	P207	10	FBLD DIFF PR
4207	P207		DIFFERENTIAL PRESSURE-FWD BLADE (85-35)
4208	P208	10	FBLD DIFF PR
4208	P208		DIFFERENTIAL PRESSURE-FWD BLD (85-47)
4209	P209	10	FBLD DIFF PR
4209	P209		DIFFERENTIAL PRESSURE-FWD BLD (85-63)
4210	P210	10	FBLD DIFF PR
4210	P210		DIFFERENTIAL PRESSURE-FWD BLD (85-77)
4211	P211	10	FBLD DIFF PR
4211	P211		DIFFERENTIAL PRESSURE-FWD BLD (85-88)
4212	P212	10	FBLD ABS PR
4212	P212		ABSOLUTE PRESSURE PAIR-FWD BLADE (90-2)
4213	P213	10	FBLD ABS PR
4213	P213		ABSOLUTE PRESSURE PAIR-FWD BLADE (90-9)
4214	P214	10	FBLD ABS PR
4214	P214		ABSOLUTE PRESSURE PAIR-FWD BLD (90-23)
4215	P215	10	FBLD DIFF PR
4215	P215		DIFFERENTIAL PRESSURE-FWD BLD (90-35)
4216	P216	10	FBLD DIFF PR
4216	P216		DIFFERENTIAL PRESSURE-FWD BLD (90-47)
4217	P217	10	FBLD DIFF PR
4217	P217		DIFFERENTIAL PRESSURE-FWD BLD (90-63)

DATA CODE	INSTR. CODE	DATA TYPE CODE	DESCRIPTION
4218	P218	10	FBLD DIFF PR
4218	P218		DIFFERENTIAL PRESSURE-FWD BLD (90-88)
4219	P219	10	FBLD ABS PR
4219	P219		ABSOLUTE PRESSURE PAIR-FWD BLADE (95-2)
4220	P220	10	FBLD ABS PR
4220	P220		ABSOLUTE PRESSURE PAIR-FWD BLADE (95-9)
4221	P221	10	FBLD ABS PR
4221	P221		ABSOLUTE PRESSURE PAIR-FWD BLD (95-23)
4222	P222	10.	FBLD DIFF PR
4222	P222		DIFFERENTIAL PRESSURE-FWD BLD (95-35)
4223	P223	10	FBLD DIFF PR
4223	P223		DIFFERENTIAL PRESSURE-FWD BLD (95-47)
4224	P224	10	FBLD DIFF PR
4224	P224		DIFFERENTIAL PRESSURE-FWD BLD (95-63)
4225	P225	10	FBLD DIFF PR
4225	P225		DIFFERENTIAL PRESSURE-FWD BLD (95-88)
4226	P226	10	FBLD ABS PR
4226	P226		ABSOLUTE PRESSURE PAIR-FWD BLADE (98-2)
4227	P227	10	FBLD ABS PR
4227	P227		ABSOLUTE PRESSURE PAIR-FWD BLADE (98-9)
4228	P228	10	FBLD ABS PR
4228	P228		ABSOLUTE PRESSURE PAIR-FWD BLD (98-23)
4229	P229	10	FBLD DIFF PR
4229	P229		DIFFERENTIAL PRESSURE-FWD BLD (98-47)
4230	P230	10	FBLD DIFF PR
4230	P230		DIFFERENTIAL PRESSURE-FWD BLD (98-77)
4231	P231	13	ABLD ABS PR
4231	P231		ABSOLUTE PRESSURE PAIR-AFT BLADE (25-2)
4232	P232	13	ABLD ABS PR
4232	P232		ABSOLUTE PRESSURE PAIR-AFT BLADE (25-9)
4233	P233	13	ABLD ABS PR
4233	P233		ABSOLUTE PRESSURE PAIR-AFT BLD (25-23)
4234	P234	13	ABLD DIFF PR
4234	P234		DIFFERENTIAL PRESSURE AFT BLADE (25-47)
4235	P235	13	ABLD DIFF PR
4235	P235		DIFFERENTIAL PRESSURE-AFT BLADE (25-77)

DATA CODE	INSTR. CODE	DATA TYPE CODE	DESCRIPTION
4236	P236	13	ABLD ABS PR
4236	P236		ABSOLUTE PRESSURE PAIR-AFT BLADE (40-2)
4237	P237	13	ABLD ABS PR
4237	P237		ABSOLUTE PRESSURE PAIR-AFT BLADE (40-9)
4238	P238	13	ABLD ABS PR
4238	P238		ABSOLUTE PRESSURE PAIR-AFT BLD (40-23)
4239	P239	13	ABLD DIFF PR
4239	P239		DIFFERENTIAL PRESSURE-AFT BLADE (40-47)
4240	P240	13	ABLD DIFF PR
4240	P240		DIFFERENTIAL PRESSURE-AFT BLADE (40-77)
4241	P241	13	ABLD ABS PR
4241	P241		ABSOLUTE PRESSURE PAIR-AFT BLADE (55-2)
4242	P242	13	ABLD ABS PR
4242	P242		ABSOLUTE PRESSURE PAIR-AFT BLADE (55-9)
4243	P243	13	ABLD ABS PR
4243	P243		ABSOLUTE PRESSURF PAIR-AFT BLD (55-23)
4244	P244	13	ABLD DIFF PR
4244	P244		DIFFERIAL PRESSURE-AFT BLADE (55-34)
4245	P245	13	ABLD DIFF PR
4245	P245		DIFFERENTIAL PRESSURE-AFT BLADE (55-47)
4246	P246	13	ABLD DIFF PR
4246	P246		DIFFERENTIAL PRESSURE-AFT BLD (55-63)
4247	P247	13	ABLD DIFF PR
4247	P247		DIFFERENTIAL PRFSSURE-AFT BLD (55-92)
4248	P248	13	ABLD ABS PR
4248	P248		ABSOLUTE PRESSURE PAIR-AFT BLADE (75-2)
4249	P249	13	ABLD ABS PR
4249	P249		ABSOLUTE PRESSURE PAIR-AFT BLADE (75-9)
4250	P250	13	ABLD ABS PR
4250	P250		ABSOLUTE PRESSURE PAIR-AFT BLD (75-23)
4251	P251	13	ABLD DIFF PR
4251	P251		DIFFERENTIAL PRESSURE-AFT BLADE (75-35)
4252	P252	13	ABLD DIFF PR
4252	P252		DIFFERENTIAL PRESSURE-AFT BLADE (75-47)
4253	P253	13	ABLD DIFF PR
4253	P253		DIFFERENTIAL PRESSURE-AFT BLADE (75-63)

DATA CODE	INSTR. CODE	DATA TYPE CODE	DESCRIPTION
4254	P254	13	ABLD DIFF PR
4254	P254		DIFFERENTIAL PRESSURE-AFT BLADE (75-88)
4255	P255	13	ABLD ABS PR
4255	P255		ABSOLUTE PRESSURE PAIR-AFT BLADE (85-2)
4256	P256	13	ABLD ABS PR
4256	P256		ABSOLUTE PRESSURE PAIR-AFT BLADE (85-4)
4257	P257	13	ABLD ABS PR
4257	P257		ABSOLUTE PRESSURE PAIR-AFT BLADE (85-9)
4258	P258	13	ABLD ABS PR
4258	P258		ABSOLUTE PRESSURE PAIR-AFT BLD (85-13)
4259	P259	13	ABLD ABS PR
4259	P259		ABSOLUTE PRESSURE PAIR- AFT BLD (85-17)
4260	P260	13	ABLD ABS PR
4260	P260		ABSOLUTE PRESSURE PAIR-AFT BLD (85-23)
4261	P261	13	ABLD DIFF PR
4261	P261		DIFFERENTIAL PRESSURE-AFT BLADE (85-35)
4262	P262	13	ABLD DIFF PR
4262	P262		DIFFERENTIAL PRESSURE-AFT BLADE (85-47)
4263	P263	13	ABLD DIFF PR
4263	P263		DIFFERENTIAL PRESSURE-AFT BLADE (85-63)
4264	P264	13	ABLD DIFF PR
4264	P264		DIFFERENTIAL PRESSURE-AFT BLD (85-77)
4265	P265	13	ABLD DIFF PR
4265	P265		DIFFERENTIAL PRESSURE-AFT BLADE (85-88)
4266	P266	13	ABLD ABS PR
4266	P266		ABSOLUTE PRESSURE PAIR-AFT BLADE (90-2)
4267	P267	13	ABLD ABS PR
4267	P267		ABSOLUTE PRESSURE PAIR-AFT BLADE (90-9)
4268	P268	13	ABLD ABS PR
4268	P268		ABSOLUTE PRESSURE PAIR-AFT BLD (90-23)
4269	P269	13	ABLD DIFF PR
4269	P269		DIFFERENTIAL PRESSURE-AFT BLADE (90-35)
4270	P270	13	ABLD DIFF PR
4270	P270		DIFFERENTIAL PRESSURE-AFT BLADE (90-47)
4271	P271	13	ABLD DIFF PR
4271	P271		DIFFERENTIAL PRESSURE-AFT BLADE (90-63)

DATA CODE	INSTR. CODE	DATA TYPE CODE	DESCRIPTION
4272	P272	13	ABLD DIFF PR
4272	P272		DIFFERENTIAL PRESSURE-AFT BLADE (90-88)
4273	P273	13	ABLD ABS PR
4273	P273		ABSOLUTE PRESSURE PAIR-AFT BLADE (95-2)
4274	P274	13	ABLD ABS PR
4274	P274		ABSOLUTE PRESSURE PAIR-AFT BLADE (95-9)
4275	P275	13	ABLD ABS PR
4275	P275		ABSOLUTE PRESSURE PAIR-AFT BLD (95-23)
4276	P276	13	ABLD DIFF PR
4276	P276		DIFFERENTIAL PRESSURE-AFT BLADE (95-35)
4277	P277	13	ABLD DIFF PR
4277	P277		DIFFERENTIAL PRESSURE-AFT BLADE (95-47)
4278	P278	13	ABLD DIFF PR
4278	P278		DIFFERENTIAL PRESSURE-AFT BLADE (95-63)
4279	P279	13	ABLD DIFF PR
4279	P279		DIFFERENTIAL PRESSURE-AFT BLADE (95-88)
4280	P280	13	ABLD ABS PR
4280	P280		ABSOLUTE PRESSURE PAIR-AFT BLADE (98-2)
4281	P281	13	ABLD ABS PR
4281	P281		ABSOLUTE PRESSURE PAIR-AFT BLADE (98-9)
4282	P282	13	ABLD ABS PR
4282	P282		ABSOLUTE PRESSURE PAIR-AFT BLD (98-23)
4283	P283	13	ABLD DIFF PR
4283	P283		DIFFERENTIAL PRESSURE-AFT BLADE (98-47)
4284	P284	13	ABLD DIFF PR
4284	P284		DIFFERENTIAL PRESSURE-AFT BLADE (98-77)
5027	S27A	00	SNC SHFT TORQ
5027	S27A		TORQUE SYNCHRONIZING SHAFT (AFT)
5153	S153A	00	A LO CYC LOAD
5153	S153A		AFT LONG. CYC. TRIM AXIAL LOAD
8153	S153F	00	F LO CYC LOAD
8153	S153F		FWD LONG. CYC. TRIM AXIAL LOAD
5207	S207A	00	F SW AC LOAD
5207	S207A		FORWARD SWIVELING ACTUATOR-AXIAL LOAD
8207	S207D	00	F PIV AC LOAD
8207	S207D		FORWARD PIVOTING ACTUATOR-AXIAL LOAD

DATA CODE	INSTR. CODE	DATA TYPE CODE	DESCRIPTION
5208	S208A	00	A SW AC LOAD
5208	S208A		AFT SWIVELING ACTUATOR-AXIAL LOAD
8208	S208D	00	A PIV AC LOAD
8208	S208D		AFT PIVOTING ACTUATOR-AXIAL LOAD
5247	S247	20	FSHFT 180 SHR
5247	S247		FORWARD ROTOR SHAFT 0-180 DEGREES SHEAR
5248	S248	21	FSHFT 270 SHR
5248	S248		FWD ROTOR SHAFT 90-270 DEGREES SHEAR
5249	S249	24	FSHFT 180 BND
5249	S249		FWD ROTOR SHAFT 0-180 DEGREES BENDING
5250	S250	23	FSHFT 270 BND
5250	S250		FWD ROTOR SHAFT 90-270 DEGREES BENDING
5251	S251	25	FSHFT TORQUE
5251	S251		FORWARD ROTOR SHAFT TORQUE
5252	S252	22	FSHFT ALT LFT
5252	S252		FORWARD ROTOR SHAFT ALTERNATING LIFT
5253	S253	26,22	FSHFT STD LFT
5253	S253		FORWARD ROTOR SHAFT STEADY LIFT
5254	S254	30	ASHFT 180 SHR
5254	S254		AFT ROTOR SHAFT 0-180 DEGREES SHEAR
5255	S255	31	ASHFT 270 SHR
5255	S255		AFT ROTOR SHAFT 90-270 DEGREES SHEAR
5256	S256	34	ASHFT 180 BND
5256	S256		AFT ROTOR SHAFT 0-180 DEGREES BENDING
5257	S257	33	ASHFT 270 BND
5257	S257		AFT ROTOR SHAFT 90-270 DEGREES BENDING
5258	S258	35	ASHFT TORQUE
5258	S258		AFT ROTOR SHAFT TORQUE
5259	S259	36,32	ASHFT STD LFT
5259	S259		AFT ROTOR SHAFT STEADY LIFT
5260	S260	32	ASHFT ALT LFT
5260	S260		AFT ROTOR SHAFT ALTERNATING LIFT
5261	S261	40	FBLD TENSION
5261	S261		FWD RADIAL TENSION (46.16-PITCH AXIS)
5262	S262	44	FBLD FLP BEND
5262	S262		FORWARD BLADE FLAP BENDING (89.41-4.49)

DATA CODE	INSTR. CODE	DATA TYPE CODE	DESCRIPTION
5263	S263	45	FBLD CWS BEND
5263	S263		FWD BLADE CHORD BENDING (88.79-5.66)
5264	S264	43	FBLD TORSION
5264	S264		FORWARD BLADF TORSION (89.41-3.40)
5265	S265	44	FBLD FLP BEND
5265	S265		FORWARD BLADE FLAP BENDING (124.0-4.49)
5266	S266	43	FBLD TORSION
5266	S266		FORWARD BLADE TORSION (140.62-3.40)
5267	S267	44	FBLD FLP BEND
5267	S267		FWD BLADE FLAP BENDING (159.44-SP.AX.)
5268	S268	45	FBLD CWS BEND
5268	S268		FWD BLADE CHORD BENDING (159.44-SP.AX.)
5269	S269	44	FBLD FLP BEND
5269	S269		FWD BLADE FLAP BENDING (194.68-SP.AX.)
5270	S270	44	FBLD FLP BEND
5270	S270		FWD BLADE FLAP BENDING (230.95-SP.AX.)
5271	S271	45	FBLD CWS BEND
5271	S271		FWD BLADE CHORD BENDING (230.95-5.66)
5272	S272	44	FBLD FLP BEND
5272	S272		FWD BLADE FLAP BENDING (273.05-SP.AX.)
5273	S273	44	FBLD FLP BEND
5273	S273		FWD BLADE FLAP BENDING (299.92-SP.AX.)
5274	S274	45	FBLD CWS BEND
5274	S274		FWD BLADE CHORD BENDING (299.92-5.66)
5275	S275	44	FBLD FLP BEND
5275	S275		FWD BLADE FLAP BENDING (339.07-SP.AX.)
5276	S276	50	ABLD TENSION
5276	S276		AFT RADIAL TENSION (46.16-PITCH AXIS)
5277	S277	54	ABLD FLP BEND
5277	S277		AFT BLADE FLAP BENDING (89.41-4.49)
5278	S278	55	ABLD CWS BEND
5278	S278		AFT BLADE CHORD BENDING (88.79-5.66)
5279	S279	53	ABLD TORSION
5279	S279		AFT BLADE TORSION (89.41-3.40)
5280	S280	54	ABLD FLP BEND
5280	S280		AFT BLADE FLAP BENDING (124.0-4.49)

DATA CODE	INSTR. CODE	DATA TYPE CODE	DESCRIPTION
5281	S281	53	ABLD TORSION
5281	S281		AFT BLADE TORSION (140.62-3.40)
5282	S282	54	ABLD FLP BEND
5282	S282		AFT BLADE FLAP BENDING (159.44-SP.AX.)
5283	S283	55	ABLD CWS BEND
5283	S283		AFT BLADE CHORD BENDING (159.44-SP.AX.)
5284	S284	54	ABLD FLP BEND
5284	S284		AFT BLADE FLAP BENDING (194.68-SP.AX.)
5285	S285	54	ABLD FLP BEND
5285	S285		AFT BLADE FLAP BENDING (230.95-SP.AX.)
5286	S286	55	ABLD CWS BEND
5286	S286		AFT BLADE CHORD BENDING (230.95-5.66)
5287	S287	54	ABLD FLP BEND
5287	S287		AFT BLADE FLAP BENDING (273.05-SP.AX.)
5288	S288	54	ABLD FLP BEND
5288	S288		AFT BLADE FLAP BENDING (299.92-SP.AX.)
5289	S289	55	ABLD CWS BEND
5289	S289		AFT BLADE CHORD BENDING (299.92-5.66)
5290	S290	54	ABLD FLP BEND
5290	S290		AFT BLADE FLAP BENDING (339.07-SP.AX.)
5295	S295	00	FWD PITCH LNK
5295	S295		FORWARD PITCH LINK-YELLOW BLADE
5296	S296	00	AFT PITCH LNK
5296	S296		AFT PITCH LINK-YELLOW BLADE
5297	S297	24	FSHFT 180 BND
5297	S297		FWD ROTOR SHAFT 0-180 DEGREES BENDING
5298	S298	23	FSHFT 270 BND
5298	S298		FWD ROTOR SHAFT 90-270 DEGREES BENDING
5299	S299	34	ASHFT 180 BND
5299	S299		AFT ROTOR SHAFT 0-180 DEGREES BENDING
5300	S300	33	ASHFT 270 BND
5300	S300		AFT ROTOR SHAFT 90-270 DEGREES BENDING
6017	T17	05	AMBAIRTEMP S1
6017	T17		AMB (OUTSIDE) AIR TEMP RESISTANCE BULB
9017	T17	05	AMBAIRTEMP S2
9017	T17		AMB (OUTSIDE) AIR TEMP RESISTANCE BULB

DATA CODE	INSTR. CODE	DATA TYPE CODE	DESCRIPTION
7101	V101	60	VACC CKPT FLR
7101	V101		VERTICAL ACCELEROMETER COCKPIT FLOOR
7105	V105	60	VACC INST PNL
7105	V105		VERTICAL ACCELEROMETER COCKPIT PANEL
7106	V106	60	VACC CKPT FL
7106	V106		VERTICAL ACCELEROMETER COCKPIT FLOOR
7107	V107	61	LAACC CKPT FL
7107	V107		LATERAL ACCELEROMETER COCKPIT FLOOR
7115	V115	60	VACC CKPT FL
7115	V115		VERTICAL ACCELEROMETER COCKPIT FLOOR
7116	V116	61	LAACC CKPT FL
7116	V116		LATERAL ACCELEROMETER COCKPIT FLOOR
7117	V117	62	LOACC CKPT FL
7117	V117		LONGITUDINAL ACCELEROMETER COCKPIT FLR
7129	V129	60	VACC CAB FLR
7129	V129		VERT ACCELEROMETER L/H FLR STA. 160
7131	V131	60	VACC CAB FLR
7131	V131		VERT ACCELEROMETER R/H FLR STA. 160
7134	V134	60	VACC CAB FLR
7134	V134		VERT ACCELEROMETER L/H FLR STA. 240
7135	V135	61	LAACC CAB FLR
7135	V135		LATERAL ACCELEROMETER L/H FLR STA. 240
7136	V136	60	VACC CAB FLR
7136	V136		VERT ACCELEROMETER R/H FLR STA. 240
7138	V138	61	LAACC CROWN
7138	V138		LATERAL ACCELEROMETER CROWN STA. 240
7139	V139	60	VACC CAB FLR
7139	V139		VERT ACCELEROMETER L/H FLR STA. 320
7141	V141	60	VACC CAB FLR
7141	V141		VERT ACCELEROMETER R/H FLOOR STA. 320
7145	V145	60	VACC CAB FLR
7145	V145		VERT ACCELEROMETER L/H FLOOR STA. 400
7146	V146	61	LAACC CAB FLR
7146	V146		LATERAL ACCELEROMETER L/H FLR STA. 400
7147	V147	60	VACC CAB FLR
7147	V147		VERTICAL ACCELEROMETER R/H FLR STA. 400

DATA CODE	INSTR. CODE	DATA TYPE CODE	DESCRIPTION
7149	V149	61	LAACC CROWN
7149	V149		LATERAL ACCELEROMETER CROWN STA. 400
7150	V150	60	VACC CAB FLR
7150	V150		VERT ACCELEROMETER L/H FLOOR STA. 482
7151	V151	61	LAACC CAB FLR
7151	V151		LATERAL ACCELEROMETER L/H FLR STA. 482
7152	V152	62	LOACC CAB FLR
7152	V152		LONG. ACCELEROMETER L/H FLOOR STA. 482
7153	V153	60	VACC CAB FLR
7153	V153		VERTICAL ACCELEROMETER R/H FLR STA. 482
7156	V156	61	LAACC CROWN
7156	V156		LATERAL ACCELEROMETER CROWN STA. 482
7163	V163	60	VACC AFT DECK
7163	V163		VERTICAL ACCELEROMETER AFT DECK
7164	V164	61	LAACC AFT DEK
7164	V164		LATERAL ACCELEROMETER AFT DECK
7165	V165	62	LOACC AFT DEK
7165	V165		LONGITUDINAL ACCELEROMETER AFT DECK
7166	V166	60	VACC AFT DECK
7166	V166		VERTICAL ACCELEROMETER DECK STA. 572
7167	V167	61	LAACC AFT DEK
7167	V167		LAT ACCELEROMETER DECK STA. 572 W.L. 72
7168	V168	62	LOACC AFT DEK
7168	V168		LONG ACCELEROMETER DECK STA. 572 WL 72
7174	V174	96	VACC THR BRNG
7174	V174		VERT ACCELEROMETER AFT THRUST BEARING
7175	V175	61	LAACC THR BRN
7175	V175		LAT ACCELEROMETER AFT THRUST BEARING
7197	V197	97	VACC FWD XMSN
7197	V197		VERT ACCELEROMETER FWD XMSN FWD FOOT
7198	V198	61	LAACC FWD XMS
7198	V198		LAT ACCELEROMETER FWD XMS THRUST MOTION
7199	V199	62	LOACC FWD XMS
7199	V199		LONG ACCELEROMTR FWD XMSN THRUST MOTION
7200	V200	60	VACC FWD XMS
7200	V200		VERT ACCEL FWD XMSN RH FT THRUST MOTION

DATA CODE	INSTR. CODE	DATA TYPE CODE	DESCRIPTION
7202	V202	98	VACC FWD XMSN
7202	V202		VERT ACCELEROMETER FWD XMSN AFT FOOT
7206	V206	60	VACC L/H TANK
7206	V206		VERT ACCELEROMETER L/H TANK STA. 320
7207	V207	60	VACC R/H TANK
7207	V207		VERT ACCELEROMETER R/H TANK STA. 320
7212	V212	62	LOACC THR BRN
7212	V212		LONG ACCELEROMETER AFT THRUST BEARING
7213	V213	61	LAACC AFT XMS
7213	V213		LATERAL ACCELEROMETER-AFT XMSN
7214	V214	62	LOACC AFT XMS
7214	V214		LONGITUDINAL ACCELEROMETER-AFT XMSN

TYPE-OF-DATA CODES

A/D CODES FOR TYPE-OF-DATA (DATA TYPE CODES)

00 - ANY DATA NOT REQUIRING SPECIFIC IDENTIFICATION

01 - LINEARLY INTEGRATED MB VELOCITY PICKUP
(OUTPUT IN INCHES OF DISPLACEMENT).

02 - ACCELEROMETER (OUTPUT IN GS)

03 - INDICATED AIRSPEED (IAS) IN KNOTS

04 - PRESSURE ALTITUDE (HP) IN FEET.

05 - OUTSIDE AIR TEMPERATURE (OAT) IN DEGREES C.

06 - FORWARD FLAP ANGLE IN DEGREES.

07 - AFT FLAP ANGLE IN DEGREES.

08 - LINEARLY INTEGRATED MB VELOCITY PICKUP
(OUTPUT IN GS)

10 - DIFFERENTIAL PRESSURE PICKUP-FORWARD BLADE.

11 - PRESSURE PICKUP ON UPPER SURFACE-FORWARD BLADE.

12 - PRESSURE PICKUP ON LOWER SURFACE-FORWARD BLADE.

13 - DIFFERENTIAL PRESSURE PICKUP-AFT BLADE.

14 - PRESSURE PICKUP ON UPPER SURFACE-AFT BLADE.

15 - PRESSURE PICKUP ON LOWER SURFACE-AFT BLADE.

16 - FORWARD BLADE LAG ANGLE

17 - AFT BLADE LAG ANGLE

20 - FX (FORWARD SHAFT SHEAR 0 DEGREE-180 DEGREES)

21 - FY (FORWARD SHAFT SHEAR 90 DEGREES-270 DEGREES)

22 - FZ (FORWARD SHAFT ALTERNATING (AND STEADY) LIFT

23 - MX (FORWARD SHAFT BEND 90 DEGREES-270 DEGREES)

24 - MY (FORWARD SHAFT BEND 0 DEGREES-180 DEGREES)

25 - MZ (FORWARD SHAFT ALTERNATING (AND STEADY) TORQUE

26 - FZS (FORWARD SHAFT OPTIONAL STEADY LIFT)

27 - MZS (FORWARD SHAFT OPTIONAL STEADY TORQUE)

30 - FX (AFT SHAFT SHEAR 0 DEGREE-180 DEGREES)

31 - FY (AFT SHAFT SHEAR 90 DEGREES-270 DEGREES)

32 - FZ (AFT SHAFT ALTERNATING (AND STEADY) LIFT

33 - MX (AFT SHAFT BEND 90 DEGREES-270 DEGREES)

34 - MY (AFT SHAFT BEND O DEGREE-180 DEGREES)

35 - MZ (AFT SHAFT ALTERNATING (AND STEADY) TORQUE

36 - FZS (AFT SHAFT OPTIONAL STEADY LIFT)

37 - MZS (AFT SHAFT OPTIONAL STEADY TORQUE)

40 - FX (FORWARD BLADE RADIAL TENSION)

41 - FY (FORWARD BLADE CHORD SHEAR)

42 - FZ (FORWARD BLADE FLAP SHEAR)

43 - MX (FORWARD BLADE TORQUE)

44 - MY (FORWARD BLADE FLAP BEND)

45 - MZ (FORWARD BLADE CHORD BEND)

46 - FXS(FORWARD BLADE OPTIONAL STEADY RADIAL TENSION)

50 - FX (AFT BLADE RADIAL TENSION)

51 - FY (AFT BLADE CHORD SHEAR)

52 - FZ (AFT BLADE FLAP SHEAR)

53 - MX (AFT BLADE TORQUE)

54 - MY (AFT BLADE FLAP BEND)

55 - MZ (AFT BLADE CHORD BEND)

56 - FXS(AFT BLADE OPTIONAL STEADY RADIAL TENSION)

60 - VERT ACCEL (OUTPUT IN GS)

61 - LAT ACCEL (OUTPUT IN GS)

62 - LONG ACCEL (OUTPUT IN GS)

90 - FWD YELLOW ROTOR HUB ACCELEROMETER

91 - FWD GREEN ROTOR HUB ACCELEROMETER

92 - FWD RED ROTOR HUB ACCELEROMETER

93 - AFT YELLOW ROTOR HUB ACCELEROMETER

94 - AFT GREEN ROTOR HUB ACCELEROMETER

95 - AFT RED ROTOR HUB ACCELEROMETER

96 - VERT ACCELEROMETER - AFT THRUST BEARING

97 - VERT ACCELEROMETER - FWD XMSN FWD FOOT

98 - VERT ACCELEROMETER - FWD XMSN AFT FOOT

MANEUVER CODES

CODE	MANEUVER
1	FWD FLT INC HOVER + SLIGHT DIVE
2	TURN RT
3	TURN LT
4	SIDEWARD FLT RT
5	SIDEWARD FLT LT
6	REARWARD FLT
7	FLARE
8	CLIMB
9	PULL UP SYMM
10	PULL UP ROLLING RT
11	PULL UP ROLLING LT
12	PUSH OVER
13	PARTIAL POWER DESCENT
14	AUTOROTATION
15	AUTOROTATION-ENTRY
16	AUTOROTATION-RECOVERY
17	DIVE
18	DIVE-ENTRY
19	DIVE-RECOVERY
20	REVERSAL-CP
21	REVERSAL-LONG
22	REVERSAL-LAT
23	REVERSAL-DIR
24	ROLL RT INC RT LAT STEP OR PULSE
25	ROLL LT INC LT LAT STEP OR PULSE
26	YAW RT INC RT PED STEP OR PULSE OR LT SIDESLIP
27	YAW LT INC LT PED STEP OR PULSE OR RT SIDESLIP
28	THROTTLE CHOP INC ENGINE FAILURE,SIMULATED,SING OR MULT
29	LANDING INC TOUCHDOWN OR ROLL-ON
30	GROUND RUN INC TRACE,TAXI,INSTABILITY
31	TAKE-OFF
32	ACCELERATION
33	DECELERATION
34	CONTINIOUS TAKE UP OF LOAD
35	CONTINIOUS REDUCTION OF LOAD
36	STEADY PULL OF LOAD
37	CABLE RELEASE
38	PARTIAL POWER DESCENT RECOVERY
39	PULL-UP FROM AUTOROTATION
40	LONGITUDINAL PULSE OR STEP INPUT
99	SAS FAILURES OR MISCELLANEOUS MANEUVERS

PHASE CODES

PHASE CODE	RECORD PATH	IRIG BAND	CENTER FREQ	CIRCUIT IDENTIFICATION
01	F	5	1.3	STRAIN GAGE VIA VCO VS IRIG BAND 13
02	F	6	1.7	STRAIN GAGE VIA VCO VS IRIG BAND 13
03	F	7	2.3	STRAIN GAGE VIA VCO VS IRIG BAND 13
04	F	8	3.0	STRAIN GAGE VIA VCO VS IRIG BAND 13
05	F	9	3.9	STRAIN GAGE VIA VCO VS IRIG BAND 13
06	F	10	5.4	STRAIN GAGE VIA VCO VS IRIG BAND 13
07	F	11	7.35	STRAIN GAGE VIA VCO VS IRIG BAND 13
08	F	12	10.5	STRAIN GAGE VIA VCO VS IRIG BAND 13
09	F	13	14.5	STRAIN GAGE VIA VCO VS IRIG BAND 13
10	F	14	22.0	STRAIN GAGE VIA VCO VS IRIG BAND 13
11	F	15	30.0	STRAIN GAGE VIA VCO VS IRIG BAND 13
12	F	16	40.0	STRAIN GAGE VIA VCO VS IRIG BAND 13
17	G	9	3.9	BLADE PRESS VIA VCO VS IRIG BAND 13
18	G	10	5.4	BLADE PRESS VIA VCO VS IRIG BAND 13
19	G	11	7.35	BLADE PRESS VIA VCO VS IRIG BAND 13
20	G	12	10.5	BLADE PRESS VIA VCO VS IRIG BAND 13
21	G	13	14.5	BLADE PRESS VIA VCO VS IRIG BAND 13
22	G	14	22.0	BLADE PRESS VIA VCO VS IRIG BAND 13
23	G	15	30.0	BLADE PRESS VIA VCO VS IRIG BAND 13
24	G	16	40.0	BLADE PRESS VIA VCO VS IRIG BAND 13
25	H	5	1.3	DONNER ACCEL VIA VCO VS IRIG BAND 13
26	H	6	1.7	DONNER ACCEL VIA VCO VS IRIG BAND 13
27	H	7	2.3	DONNER ACCEL VIA VCO VS IRIG BAND 13
28	H	8	3.0	DONNER ACCEL VIA VCO VS IRIG BAND 13
29	H	9	3.9	DONNER ACCEL VIA VCO VS IRIG BAND 13
30	H	10	5.4	DONNER ACCEL VIA VCO VS IRIG BAND 13
31	H	11	7.35	DONNER ACCEL VIA VCO VS IRIG BAND 13
32	H	12	10.5	DONNER ACCEL VIA VCO VS IRIG BAND 13
33	H	13	14.5	DONNER ACCEL VIA VCO VS IRIG BAND 13
34	H	14	22.0	DONNER ACCEL VIA VCO VS IRIG BAND 13
35	H	15	30.0	DONNER ACCEL VIA VCO VS IRIG BAND 13
36	H	16	40.0	DONNER ACCEL VIA VCO VS IRIG BAND 13
00				NO CORRECTION

CONTROL WORDS

A/D CONTROL WORDS

WORD 1 NUMBER OF HARMONICS OUTPUT FROM M43-TENS

WORD 2 NUMBER OF HARMONICS OUTPUT FROM M43-UNITS

WORD 3 BLADE PRESSURE ANALYSIS (M47) DESIRED
1 = YES
0 = NO

APPENDIX II

SIGN CONVENTIONS AND ZERO REFERENCE POSITIONS

Parameter	Positive Direction	Reference Position
Acceleration	Upward, forward, to right, and out	Neutral
Actuator travel	Extension	Fully retracted
Airspeed	Increasing airspeed (forward and right sideward flight)	Zero airspeed
Altitude	Increasing altitude	Sea level standard
Angle of attack	Nose up (with reference to relative wind)	Waterlines of fuselage parallel with relative wind
Blade flap angle	Up	Straight out (blade axis perpendicular to shaft)
Blade pitch angle	Leading edge up	Angle between chordline and plane perpendicular to shaft at ℄ of rotation with linearly projected blade twist
Blade lag angle	Lead	Blade axis outboard of lag pin in line with blade axis inboard of lag pin
Blade flap bending moment	Flap up (tension in lower fibers)	No-load condition
Blade torsion	Leading edge up with root end fixed	No-load condition
Blade chord bend	Tension in forward fibers	No-load condition

Parameter	Positive Direction	Reference Position
Blade tension	Tension	No-load condition
Blade pressure	Lift (lower surface pressure minus upper surface pressure)	No-lift condition
Pitch attitude	Nose up	Fuselage waterlines and horizon parallel
Roll attitude	Right side down	Waterlines and horizon parallel
Rotor shaft loads	See Figure 21	1g load condition
Sideslip angle	Nose left (with reference to relative wind)	Longitudinal plane of aircraft contains relative wind vector
Yaw heading	Nose right	Zero at start of each record

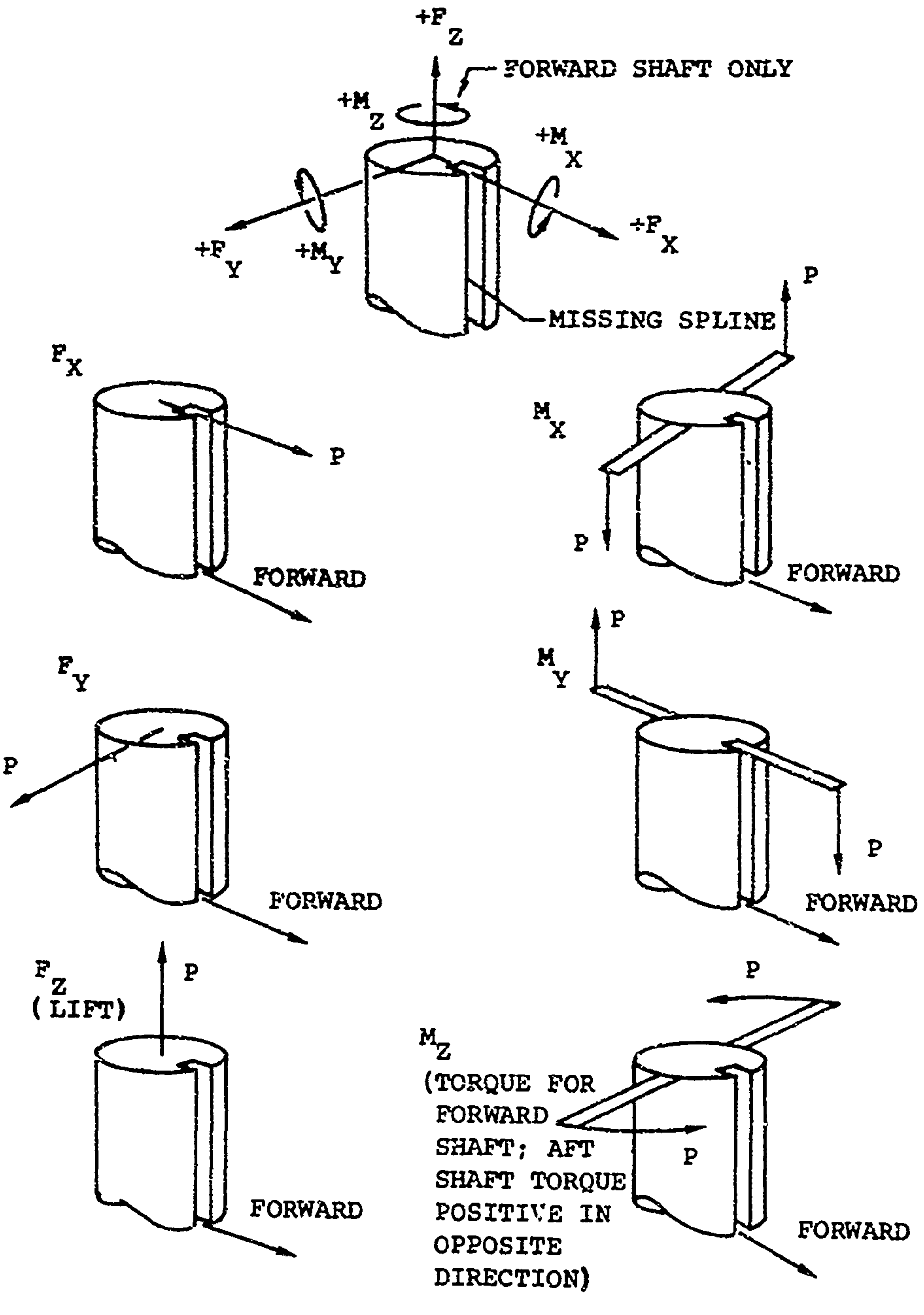


Figure 21. Sign Conventions for Forward and Aft Vertical Shaft Loads and Moments.

APPENDIX III

COMPARISON OF THE TRAPEZOIDAL RULE AND THE LEGENDRE-GAUSS NUMERICAL INTEGRATION METHODS

INTRODUCTION

This appendix compares two numerical integration techniques used in integrating blade pressure data. One is the well-known Trapezoidal Rule, which is extremely simple to use, and the other is the Legendre-Gauss method described by Hildebrand.* The latter method was modified and used by Bell Helicopter Company to integrate pressure data for an airloads study.** Part of their modification consisted of dividing the chord length into two parts (0- to 26-percent chord and 26- to 100-percent chord) and then applying the Legendre-Gauss method to each interval separately.

DISCUSSION

To compare the two methods, an analytical expression for a typical pressure distribution is formed (Figure 22), and then each of the two methods is used to determine the area under the curve. Only the 0- to 26-percent-chord interval is considered.

In the case where four pressure pickups are to be utilized in the interval $0 \leq x \leq 2.6$ (0- to 26-percent chord), the best chordwise locations for them according to the Legendre-Gauss method are 1.80523-, 8.58026-, 17.41974-, and 24.19476-percent chord. In a prior airloads study,** the values of the chordwise locations used were 2-, 9-, 17-, and 23-percent chord; hence, a comparison will be made using both sets of chord locations in each of the methods of numerical integration (the Legendre-Gauss chordwise locations will be used for the trapezoidal method also).

Analytically integrating the pressure distribution of Figure 22 over the interval $0 \leq x \leq 2.6$ yields a value of 1.492707 for the exact value. Determining this integral numerically, using the Legendre-Gauss method, we have

---

*F.B. Hildebrand, Introduction to Numerical Analysis, McGraw-Hill Book Co., Inc., New York, N.Y., 1956, pp 323-325.

**F. B. Burpo, Measurement of Dynamic Airloads on a Full-Scale Semirigid Rotor, USATRECOM Report No. TCREC TR 62-42, Bell Helicopter Co. Report No. 525-099-001, December 1962.

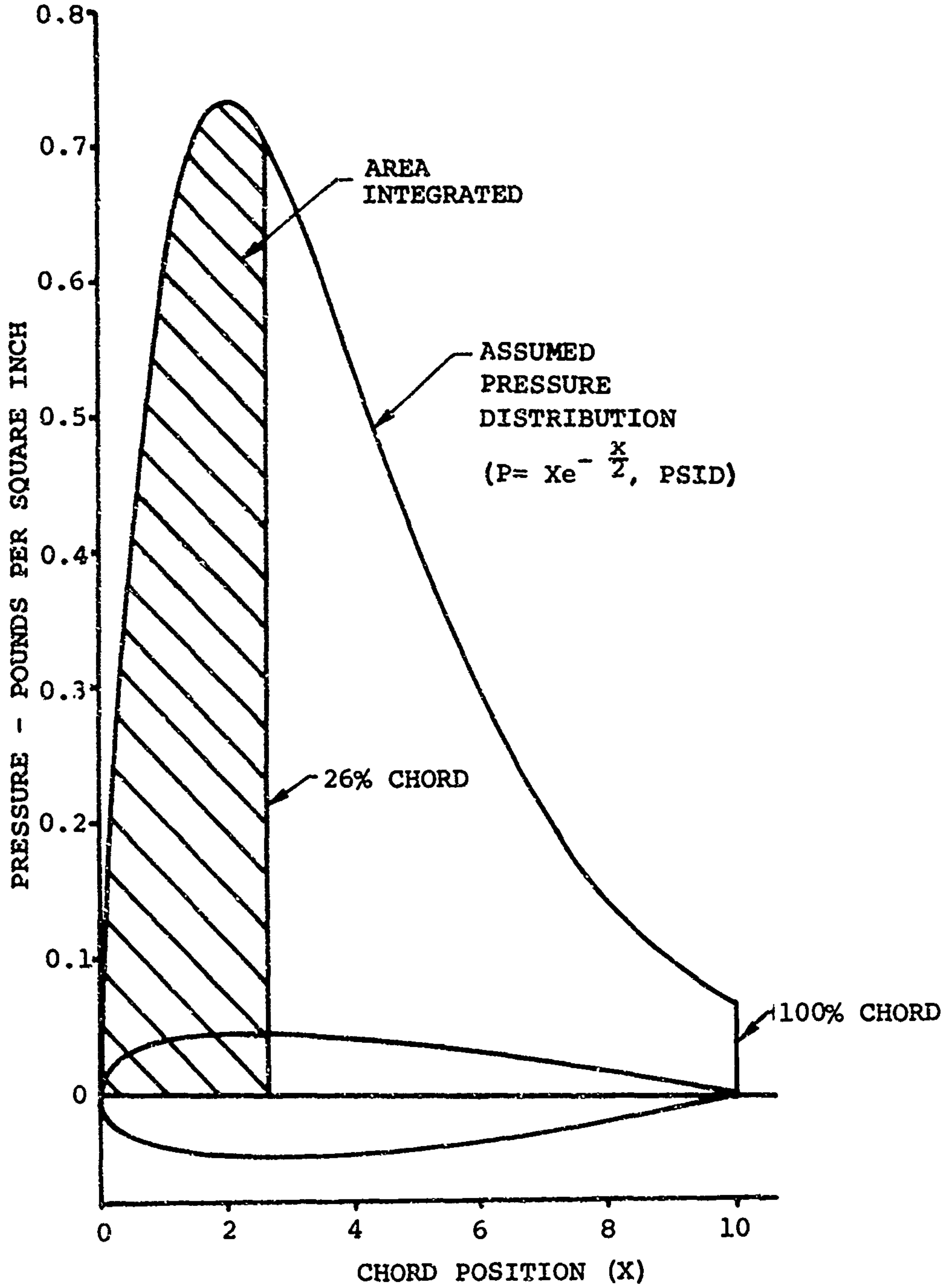


Figure 22. Analytical Pressure Distribution Used for Comparison of Numerical Integration Methods.

$$\int_0^{2.6} f(x)\,dx = \sum_{k=1}^{4} H_k\, f(x_k), \tag{63}$$

where H_k are weighting functions and $f(x_k)$ is the value of the function being integrated, evaluated at chord position x_k. The exact values of H_k and x_k (given by Abramowitz*), together with the approximate values from the prior airloads study,** are shown in Table XI.

TABLE XI

EXACT AND APPROXIMATE CHORDWISE POSITIONS (x_k) AND WEIGHTING VALUES (H_k) FOR USE IN LEGENDRE-GAUSS METHOD OF NUMERICAL INTEGRATION

	Exact Values*		Approximate Values**	
k	x_k	H_k	x_k	H_k
1	0.180523	0.452212	0.2	0.44
2	0.858026	0.847789	0.9	0.82
3	1.741974	0.847789	1.7	0.82
4	2.419476	0.452212	2.3	0.44

*Abramowitz, op. cit.
**Burpo, op. cit.

Using these values, equation (63) yields

$$\sum_{k=1}^{4} H_k\, f(x_k) = 1.492708$$

and

$$\sum_{k=1}^{4} H_k\, f(x_k) = 1.466447$$

when using the exact values and the values in the prior airloads study** respectively.

*Milton Abramowitz and Irene A. Stegun, Handbook of Mathematical Functions with Formulas and Graphs, U.S. Department of Commerce, National Bureau of Standards, Applied Mathematics Series No. 55.
**Burpo, op. cit.

The trapezoidal rule yields, for the same integration,

$$\int_0^{2.6} f(x)\ dx = \tfrac{1}{2} \sum_{k=0}^{5} \left[(x_{k+1}) \quad \left[f(x_{k+1}) + f(x_k) \right] \right]$$

$$= 1.449736$$

and

$$= 1.454464$$

when using the exact values and the values in the prior study, respectively. The values obtained are close to the exact values and are almost as good as the Legendre-Gauss method when the values of the prior study are used. These results emphasize the necessity for establishing exact chord locations in order to make optimum use of the Legendre-Gauss method. Such a condition is not easily satisfied due to other constraints on physically locating pressure pickups on a rotor blade.

Table XII summarizes the results of both types of numercial integration for the two sets of chordwise locations (x_k values).

TABLE XII
COMPARISON OF RESULTS OF INTEGRATION AS DETERMINED BY LEGENDRE-GAUSS AND TRAPEZOIDAL NUMERICAL INTEGRATION METHODS FOR BOTH APPROXIMATE AND EXACT VALUES OF CHORDWISE POSITIONS (x_k) AND WEIGHTING VALUES (H_k)

Chordwise Locations Used	Legendre-Gauss Method	Trapezoidal Rule
Exact values* of x_k	1.492708	1.449736
Approximate values** of x_k	1.466448	1.454464

*Abramowitz, op. cit.
**Burpo, op. cit.

CONCLUSIONS

The Legendre-Gauss method of numerical integration is superior to the Trapezoidal Rule in determining the value of an airload integral, at least for a well-behaved function such as that used in the example. This conclusion does not necessarily apply when

the function has many points of inflection, such as the more interesting dynamic airloads data are known to contain. This conclusion was not explored further, however, due to the unknown applicability of this method for calculating airload pitching moments and due to the critical restraint of this method on the pickup location. If the abscissa values are not located exactly, as was the case in locating chordwise positions for the pressure pickups on the tested rotor blades, the high degree of accuracy of the Legendre-Gauss method has no advantage over the simpler Trapezoidal Rule, which has therefore been utilized for the Dynamic Airloads Program.

APPENDIX IV

LOOKUP TABLES

TEMPERATURE AND LINEARITY CORRECTIONS

Tables XIII and XIV list the corrections for temperature and linearity used in the Correction Program (M51).

DATA FROM FUNCTIONAL CHECK F394

Table XV lists data obtained from functional check F394 as percent deviation of full-scale values.

TABLE XIII

TEMPERATURE CORRECTIONS USED IN CORRECTION PROGRAM (M51)

Data Code	Zero Shift Constant (K_Z)	Sensitivity Shift Constant (K_S)
4180	0.002200	0.000845
4181	-0.00094	0.001270
4185	0.00070	0.000815
4186	-0.00170	0.000630
4190	-0.00105	0.000605
4191	0.00094	0.000725
4192	-0.00157	0.000332
4193	-0.00091	0.001450
4197	-0.00266	0.000695
4198	0.00021	0.000875
4199	-0.00206	0.001030
4200	0.00314	0.001480
4207	0.00248	0.000664
4208	0.00199	0.000906
4209	0.00148	0.000454
4210	-0.00130	0.000815
4211	0.00088	0.001030
4215	0.00067	0.001330
4216	-0.00097	0.000785
4217	-0.00151	0.001180
4218	0.00254	0.001390

TABLE XIII - Continued

Data Code	Zero Shift Constant (K_Z)	Sensitivity Shift Constant (K_S)
4222	0.00033	0.000570
4223	0.00151	0.000725
4224	0.00260	0.001025
4225	0.00060	0.000514
4229	0.00193	0.001210
4230	-0.00196	0.001570
4234	0.00202	0.000665
4235	0.00103	0.000574
4239	0.00166	0.001000
4240	0.00057	0.001240
4244	0.00051	0.000935
4245	0.00320	0.025000
4246	-0.00133	0.001090
4247	0.00048	0.001420
4251	0.00082	0.000845
4252	-0.00140	0.026000
4253	-0.00338	0.001120
4254	0.00314	0.001090
4261	0.00260	0.029000
4262	0.00190	0.000604
4263	0.00142	0.000635
4264	-0.00100	0.000423
4265	0.00281	0.000514
4269	0.00054	0.000574
4270	0.00118	0.000755
4271	-0.00170	0.012000
4272	0.00199	0.000453
4276	-0.00048	0.000655
4277	0.00170	0.025000
4278	0.00232	0.001480
4279	0.00227	0.000875
4283	0.00196	0.000635
4284	0.00124	0.000423

TABLE XIV

LINEARITY CORRECTIONS USED IN CORRECTION PROGRAM (M51)

Data Code 4193		Data Code 4198		Data Code 4210	
V_{ZS} (psi)	K_L (psi)	V_{ZS} (psi)	K_L (psi)	V_{ZS} (psi)	K_L (psi)
1.987	0.061	5.000	-0.078	1.987	0.000
1.455	0.019	4.000	-0.030	1.455	-0.004
0.723	-0.022	3.000	0.013	0.723	-0.010
0.361	-0.035	2.000	0.034	0.361	0.046
-0.361	-0.037	1.000	0.048	0.000	-0.010
-0.723	-0.027	-1.000	0.035	-0.361	-0.012
-1.084	-0.010	-2.000	0.016	-0.723	-0.011
-1.455	0.017	-3.000	-0.005	-1.084	-0.005
-1.987	0.070	-5.000	-0.014	-1.987	0.010
Data Code 4229		Data Code 4230		Data Code 4244	
V_{ZS} (psi)	K_L (psi)	V_{ZS} (psi)	K_L (psi)	V_{ZS} (psi)	K_L (psi)
9.823	0.025	4.912	0.096	5.000	0.132
7.367	0.058	2.947	0.012	4.000	0.060
4.912	0.015	1.965	-0.020	2.000	-0.026
1.228	-0.007	0.982	-0.044	1.000	-0.050
-1.228	-0.055	-0.982	-0.052	-1.000	-0.047
-3.684	-0.053	-1.965	-0.036	-2.000	-0.029
-6.140	-0.010	-2.947	0.002	-3.000	0.009
-8.595	0.071	-3.929	0.054	-4.000	0.060
-9.823	0.143	-4.912	0.126	-5.000	0.132
Data Code 4252		Data Code 4262		Data Code 4270	
V_{ZS} (psi)	K_L (psi)	V_{ZS} (psi)	K_L (psi)	V_{ZS} (psi)	K_L (psi)
4.912	0.042	4.912	-0.155	9.823	-0.134
3.684	0.029	2.947	-0.007	7.859	-0.038
2.456	0.004	1.965	0.036	5.894	0.016
1.228	-0.017	0.982	0.061	3.929	0.037
-1.228	-0.029	-0.982	0.070	-1.965	0.049
-2.456	-0.011	-1.965	0.038	-3.929	0.029
-3.684	0.020	-2.947	-0.011	-5.894	-0.105
-4.912	0.079	-3.929	-0.074	-7.859	-0.014
		-4.912	-0.149	-9.823	-0.021

TABLE XIV-Continued

Data Code 4271		Data Code 4277		Data Code 4284	
V_{ZS} (psi)	K_L (psi)	V_{ZS} (psi)	K_L (psi)	V_{ZS} (psi)	K_L (psi)
4.912	-0.111	9.823	0.119	4.912	-0.144
3.684	-0.033	7.859	0.080	3.684	-0.038
2.456	0.019	5.894	0.028	2.456	0.022
1.228	0.042	1.965	-0.065	1.228	0.051
-1.228	0.037	-1.965	-0.068	-1.228	0.050
-2.456	0.008	-3.929	-0.046	-2.456	0.010
-3.684	-0.038	-5.894	0.001	-3.684	0.049
-4.912	-0.089	-7.859	0.075	-4.912	-0.114
		-9.823	0.181		

TABLE XV
DATA FROM FUNCTIONAL CHECK F394

Parameter	Ident		Data Code	Record 1 Baseline before in-flight cal (% dev of full scale)	Record 2 Baseline after in-flight cal (% dev of full scale)	Record 3 Signal simulation = cal equiv (% dev of full scale)
FROT	ACC	YBLD	1044	-1.23	-0.22	-1.15
FROT	ACC	GBLD	1045	-0.88	0.13	-0.30
FROT	ACC	RBLD	1046	-0.82	-0.26	-0.25
AROT	ACC	YBLD	1047	0.13	1.27	1.40
AROT	ACC	GBLD	1048	0.19	1.14	2.25
AROT	ACC	RBLD	1049	0.25	0.88	2.00
FWD	BLD	PITCH	2024	-0.18	-0.79	-1.40
AFT	BLD	PITCH	2025	0.16	0.00	-1.00
FWD	BLD	FLAP	2026	-0.33	0.12	-1.10
AFT	BLD	FLAP	2027	-0.05	-0.13	-1.60
FWD	BLD	LAG	2028	0.02	0.29	0.55
AFT	BLD	LAG	2029	-0.18	-0.09	0.05
FBLD	ABS	PR	4177	-1.30	1.10	-2.10
FBLD	ABS	PR	4178	-1.35	0.18	-0.40
FBLD	ABS	PR	4179	-4.75	1.60	-1.10
FBLD	DIFF	PR	4180	-1.20	1.80	0.70
FBLD	ABS	PR	4182	1.70	-0.25	-0.90
FBLD	ABS	PR	4183	0.15	0.95	-1.70
FBLD	ABS	PR	4184	-0.60	-0.62	-1.70
FBLD	ABS	PR	4187	-0.85	0.30	-1.15
FBLD	DIFF	PR	4190	2.45	-0.15	-4.10
FBLD	DIFF	PR	4191	0.30	1.10	-2.55
FBLD	DIFF	PR	4193	-0.80	0.10	-1.20
FBLD	DIFF	PR	4192	-0.50	0.75	-0.20
FBLD	ABS	PR	4194	-0.35	-0.26	-1.10
FBLD	ABS	PR	4195	-0.51	-0.34	-0.50
FBLD	ABS	PR	4196	-0.85	-0.42	-0.80
FBLD	DIFF	PR	4197	-0.53	-0.50	-1.05
FBLD	DIFF	PR	4186	1.00	-0.20	-2.00
FBLD	ABS	PR	4188	0.78	-0.30	-0.75
FBLD	ABS	PR	4189	-0.42	-0.62	-1.10
FBLD	ABS	PR	4201	-2.55	0.85	0.25
FBLD	ABS	PR	4202	-0.16	0.00	-0.80
FBLD	ABS	PR	4203	-0.48	-0.16	-0.55
FBLD	ABS	PR	4204	-0.48	0.00	-0.15
FBLD	ABS	PR	4205	0.15	-0.19	-0.80
FBLD	ABS	PR	4206	0.00	-0.25	-1.00

TABLE XV- Continued

Parameter Ident			Data Code	Record 1	Record 2	Record 3
FBLD	DIFF	PR	4207	-0.42	-0.45	-5.95
FBLD	DIFF	PR	4208	-0.48	-0.40	-1.35
FBLD	DIFF	PR	4209	-1.50	0.00	-1.05
FBLD	DIFF	PR	4210	-0.80	-0.80	-1.20
FBLD	DIFF	PR	4211	2.85	1.60	-1.95
FBLD	ABS	PR	4212	-0.14	0.13	-0.40
FBLD	DIFF	PR	4215	0.10	-0.38	-0.65
FBLD	DIFF	PR	4216	-1.62	0.37	-0.95
FBLD	DIFF	PR	4217	-1.23	-0.95	-1.70
FBLD	DIFF	PR	4218	1.25	-0.55	-2.00
FBLD	ABS	PR	4219	-0.77	-0.47	-1.05
FBLD	ABS	PR	4220	-0.26	-0.55	-0.75
FBLD	ABS	PR	4221	-0.40	-0.46	-0.75
FBLD	DIFF	PR	4222	-0.11	-0.37	-0.85
FBLD	DIFF	PR	4223	-2.50	0.28	-1.20
FBLD	DIFF	PR	4224	-1.10	0.25	-1.25
FBLD	DIFF	PR	4225	2.60	-1.35	-1.80
FBLD	ABS	PR	4226	-0.20	-0.51	-0.75
FBLD	ABS	PR	4227	0.06	-2.14	-1.00
FBLD	ABS	PR	4228	-0.27	-0.75	-0.25
FBLD	DIFF	PR	4229	0.67	-0.15	-0.80
ABLD	ABS	PR	4231	0.67	0.60	-1.10
ABLS	ABS	PR	4232	-1.45	-0.20	0.10
ABLD	DIFF	PR	4234	7.00	-2.50	-7.20
ABLD	DIFF	PR	4235	5.70	0.90	-4.55
ABLD	ABS	PR	4236	-0.18	0.00	-1.05
ABLD	ABS	PR	4237	3.45	0.83	0.55
ABLD	ABS	PR	4238	0.60	1.00	1.25
ABLD	DIFF	PR	4239	5.75	2.80	-2.10
ABLD	DIFF	PR	4240	0.75	0.03	-2.70
ABLD	ABS	PR	4241	-0.29	0.25	0.30
ABLD	ABS	PR	4242	-0.15	0.50	0.35
ABLD	ABS	PR	4243	1.50	2.25	0.35
ABLD	DIFF	PR	4244	7.40	-0.80	-3.75
ABLD	DIFF	PR	4245	3.15	0.80	-1.80
ABLD	DIFF	PR	4246	8.50	1.60	2.00
ABLD	DIFF	PR	4247	2.40	0.40	-2.20
ABLD	ABS	PR	4248	-0.30	0.62	1.05
ABLD	ABS	PR	4249	-0.35	0.07	1.70
ABLD	ABS	PR	4250	0.80	0.97	0.55
ABLD	DIFF	PR	4251	3.25	1.07	-0.85
ABLD	DIFF	PR	4252	0.15	-0.80	0.45
ABLD	DIFF	PR	4253	2.65	0.65	-0.05

TABLE XV- Continued

Parameter Ident			Data Code	Record 1	Record 2	Record 3
ABLD	DIFF	PR	4254	0.05	0.90	1.25
ABLD	ABS	PR	4255	-1.48	0.58	0.55
ABLD	ABS	PR	4256	0.12	0.39	0.40
ABLD	ABS	PR	4257	0.62	0.41	0.25
ABLD	ABS	PR	4258	0.92	0.57	1.00
ABLD	ABS	PR	4259	0.37	1.12	0.90
ABLD	ABS	PR	4260	0.22	0.20	0.20
ABLD	DIFF	PR	4261	-1.48	0.40	0.90
ABLD	DIFF	PR	4262	-0.15	1.28	0.75
ABLD	DIFF	PR	4263	3.70	-0.25	-2.25
ABLD	DIFF	PR	4264	-0.10	0.65	-0.15
ABLD	DIFF	PR	4265	-2.45	3.35	-2.05
ABLD	ABS	PR	4266	-0.05	0.16	0.95
ABLD	ABS	PR	4267	-0.01	0.27	0.30
ABLD	ABS	PR	4268	-0.10	0.17	-0.20
ABLD	DIFF	PR	4269	0.55	0.97	1.05
ABLD	DIFF	PR	4270	0.10	1.38	0.55
ABLD	DIFF	PR	4271	-0.05	0.47	0.30
ABLD	DIFF	PR	4272	-1.55	2.40	1.85
ABLD	ABS	PR	4273	-0.42	-0.18	0.20
ABLD	ABS	PR	4274	0.34	0.62	0.90
ABLD	ABS	PR	4275	0.29	0.55	0.95
ABLD	DIFF	PR	4276	1.08	0.47	0.40
ABLD	DIFF	PR	4277	1.88	0.73	0.35
ABLD	DIFF	PR	4278	0.40	0.05	-0.05
ABLD	DIFF	PR	4279	-3.90	0.45	0.90
ABLD	ABS	PR	4280	0.97	0.36	0.10
ABLD	ABS	PR	4281	0.19	0.65	2.10
ABLD	ABS	PR	4282	1.25	0.58	0.45
ABLD	DIFF	PR	4283	0.15	-0.02	-0.80
FSHFT	180	SHR	5247	-2.37	0.17	-3.15
FSHFT	270	SHR	5248	-1.66	-0.32	-0.85
FSHFT	180	BND	5249	0.21	-0.27	-0.15
FSHFT	270	BND	5250	-1.00	-0.22	-1.65
FSHFT	TORQUE		5251	-0.46	-0.17	-0.80
ASHFT	180	SHR	5254	-1.69	0.24	-1.10
ASHFT	270	SHR	5255	-0.02	0.73	2.90
ASHFT	180	BND	5256	0.87	0.95	2.40
ASHFT	270	BND	5257	-0.05	0.43	0.95
ASHFT	TORQUE		5258	0.22	0.35	0.30
FBLD	TENSION		5261	-0.07	-0.10	-0.50
FBLD	FLP	BEND	5262	-0.49	-0.23	-0.40
FBLD	TORSION		5264	-0.53	-0.25	-0.75
FBLD	FLP	BEND	5265	-0.22	-0.07	-1.00

TABLE XV - Continued

Parameter Ident			Data Code	Record 1	Record 2	Record 3
FBLD	FLP	BEND	5267	-0.37	-0.25	-1.50
FBLD	FLP	BEND	5269	-0.38	-0.16	-0.10
FBLD	FLP	BEND	5270	-0.54	-0.21	-0.80
FBLD	FLP	BEND	5272	-0.36	-0.23	-1.25
FBLD	FLP	BEND	5273	-0.64	-0.01	-1.50
FBLD	FLP	BEND	5275	-0.60	-0.15	-0.85
ABLD	TENSION		5276	-0.01	0.11	0.00
ABLD	FLP	BEND	5277	-0.16	-0.43	1.05
ABLD	FLP	BEND	5280	-0.17	-0.32	0.00
ABLD	FLP	BEND	5282	-0.06	-0.29	0.05
ABLD	FLP	BEND	5284	-0.13	-0.95	0.75
ABLD	FLP	BEND	5287	0.44	0.43	-0.05
ABLD	FLP	BEND	5288	-0.29	0.33	-0.45
ABLD	FLP	BEND	5290	0.44	1.14	1.90
FWD	PITCH	LNK	5295	-0.23	-0.04	-1.05
AFT	PITCH	LNK	5296	0.01	-0.08	-0.65

Unclassified
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) VERTOL DIVISION THE BOEING COMPANY Morton, Pennsylvania	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE
In-Flight Measurement of Rotor Blade Airloads, Bending Moments, and Motions, Together with Rotor Shaft Loads and Fuselage Vibration, on a Tandem Rotor Helicopter, Volume III, Data Processing and Analysis System

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Final Technical Report

5. AUTHOR(S) (First name, middle initial, last name)
Obbard, John W.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
November 1967	116	0

8a. CONTRACT OR GRANT NO. DA 44-177-AMC-124(T) b. PROJECT NO. Task 1F125901A14604 c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) USAAVLABS Technical Report 67-9C 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) D8-0382-3

10. DISTRIBUTION STATEMENT
This document has been approved for public release and sale; its distribution is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY U.S. Army Aviation Materiel Laboratories Fort Eustis, Virginia

13. ABSTRACT
An extensively instrumented tandem rotor helicopter was flight-tested to measure the rotor blade airloads and the resulting rotor blade motions and bending moments, rotor shaft loads and moments, and fuselage vibration. The voluminous output of this extensive instrumentation was processed by a fully automated data system which is described in this volume. Data were tape-recorded in sequenced-multiplexed, frequency-modulated (FM) form during flight testing. The FM signals were discriminated to analog form and were digitized by using a high-speed analog-to-digital converter. Digital data were calibrated, corrected for temperature and load interactions, and harmonically analyzed by using a series of digital computer programs. Airloads pressure data were numerically integrated to determine instantaneous blade section lift and pitching moment and the lift and pitching moment of the entire rotor blade. Data were also prepared for other analyses. The data system also included various data checks which are discussed. Substantiating tests and analyses that were performed to ensure the proper operation of this system are also presented. Data output from this program is available on a computer tape (nine-track, IBM System 360) in fully identified form for utilization in further analyses.

DD FORM 1 NOV 65 1473 REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

Unclassified
Security Classification

Unclassified
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
instrumentation data processing data analysis computers						

Unclassified
Security Classification

9623-67